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Edited by
O. M. B. BULMAN and S. R. NOCKOLDS

assisted by
PROFESSOR W. G. FEARNSIDES PROFESSOR O. T. JONES
PROFESSOR LEONARD HAWKES PROFESSOR W. J. PUGH
PROFESSOR C. E. TILLEY

CONTENTS

	PAGE
CHUBB, L. J. The Cretaceous Succession in Jamaica	177
CAREY, S. W. Wegener's South America–Africa Assembly, Fit or Misfit?	196
HUGHES. N. F. Wealden Plant Microfossils	201
FORD, T. D. The Upper Carboniferous Rocks of the Stainmore Coalfield	218
SANDERS, L. D. Structural Observations on the South-East Lizard	231
MOREL, S. W. Biotitite in the Basement Complex of Southern Nyasaland	241
DINELEY, D. L. Some Devonian Fish Remains from North Central Vestspitsbergen	255

CORRESPONDENCE

Fletcherina, a New Name for a Palaeozoic Coral Genus	261
The Ubendian in Western Tanganyika	261

REVIEW
p. 263

PUBLICATIONS RECEIVED
p. 264

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GEOLOGICAL MAGAZINE

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The Cretaceous Succession in Jamaica

By L. J. CHUBB

ABSTRACT

There are wide divergencies between the views of different authors as to the correlation of the Jamaican Cretaceous rocks, the extreme views being (*a*) that the range covered is Albian to Turonian, and (*b*) that the rocks are mainly or wholly Maestrichtian in age.

An examination of all known occurrences of the rudist genera *Barrettia* and *Titanosarcolites* in the Antillean and Central American area suggests that the oft-repeated statement that these two genera occur in association is erroneous. In Jamaica the *Barrettia* Limestone lies at least 2,500 ft. below the *Titanosarcolites* Limestone.

Six palaeontological zones may be recognized in the Cretaceous of Jamaica, each containing its own peculiar assemblage of fossils, and with very few species common to two zones. Evidence is brought forward that only the highest part, comprising the uppermost two zones, should be included in the Maestrichtian, that the underlying shale is Campanian, that the *Barrettia* Limestone and associated shales are Turonian, and that the lowest zone at present known is Cenomanian.

INTRODUCTION

IN the course of its field-work in Jamaica the Geological Survey has made a detailed study of several inliers of fossiliferous Cretaceous rocks. One of the most important is the Sunderland Inlier, which lies in St. James parish about nine miles south-east of Montego Bay. Here the basal conglomerate of the system rests on igneous rocks, and immediately above it there is a thick shale series containing a large species of *Inoceramus*. Further south a limestone overlies the shale series, yielding the rudist, *Barrettia*, succeeded by another series of shales and conglomerates, above which a higher limestone, yielding *Titanosarcolites giganteus*, has been found to be present, though poorly exposed. Thus in this inlier, previously almost unknown, there is a nearly complete sequence of Cretaceous rocks, with a total thickness of between 7,000 and 8,000 feet. The *Titanosarcolites* Limestone and its associated fossiliferous shales are well exposed in the Maldon-Vaughansfield inlier, about two miles south of the Sunderland inlier, and in the Ducketts-Catadupa inlier, some miles to the south-west, on the St. James-Westmoreland border. A small inlier south of St. Ann's

Bay, showing good sections of the *Inoceramus* Shales and *Barrettia* Limestone, has been investigated in some detail by Zans, and visited several times by the writer. The Department is at present engaged in a survey of the large Central Inlier of Cretaceous rocks in upper Clarendon. Visits have also been paid by H. R. Versey to Haughton Hall, Green Island, near the western end of the island, to collect from the *Barrettia* Limestone, and by the writer to Jerusalem Mountain about nine miles south-west of Lucea, where the highest fossiliferous Cretaceous beds are exposed, and to the district south of Port Antonio, Portland parish, where a rather different facies of Cretaceous rocks is developed.

Fossils are plentiful in many parts of the Cretaceous succession, including in approximate order of abundance lamellibranchs, gastropods, corals, and echinoids, with a few ammonoids, crustaceans, bryozoa, and annelids. The micro-fossils are not as yet well known. The fauna shows few close affinities with the Cretaceous faunas of North America or Europe, so correlation with the standard succession is difficult. Dr. L. W. Stephenson (1942) after his study of a large collection made by the late Dr. C. A. Matley could find only one species, *Hamulus onyx* Morton, common to the Upper Cretaceous of Jamaica and the Atlantic and Gulf Coastal Plain. The fauna shows greater affinities with that of the Mediterranean countries, of the neighbouring Antillean islands, and of Mexico and Guatemala, with which it has a number of species in common.

At least six palaeontological horizons may be recognized in the Cretaceous of Jamaica, the succession in descending order being—

(*f*) *Ostrea* (*Alectryonia*) Limestone
(*e*) *Titanosarcolites* (*Caprinula*) Limestone
(*d*) *Veniella* (*Roudaireia*) Shale
(*c*) *Diozoptyxis* (*Glauconia*) Shale
(*b*) *Barrettia* Limestone
(*a*) *Inoceramus* Series.

Each of the six zones contains its own peculiar assemblage of fossils, and very few species pass upwards from one zone into another. It may be possible in the future to delimit these zones more narrowly and to intercalate others, for in St. James parish *Titanosarcolites giganteus* seems to be confined to the uppermost part of a limestone 150 to 200 feet thick, and the *Veniella* fauna is restricted to the upper 150 feet of a shale series about 2,500 feet thick ; the *Diozoptyxis* fauna occurs in the lowest part of what is presumably the same shale series in St. Ann parish ; and the large species of *Inoceramus* comes at least 1,000 feet below the base of the *Barrettia* Limestone in St. Ann and 4,000 feet below in St. James. In the inliers of Upper Clarendon and

St. James the *Inoceramus* Series rests directly upon igneous rocks, and the *Titanosarcolites* Limestone is succeeded by tuffs yielding indeterminable organic remains, the *Ostrea* Limestone being known at present only at Jerusalem Mountain, Westmoreland parish.

My thanks are due to Dr. C. T. Trechmann, under whose guidance I paid my first visits to several important Jamaican Cretaceous exposures; to Prof. H. L. Hawkins for help in determining echinoids, for his company on a field-trip and for many helpful discussions during an all too brief visit to Jamaica; to Dr. Otto H. Haas of the American Museum of Natural History, to Dr. J. B. Reeside and Dr. L. W. Stephenson of the U.S. National Museum and to Dr. L. R. Cox of the British Museum (Natural History), for giving me access to their collections of Cretaceous fossils from Jamaica, other Caribbean islands, Central America, Texas, etc., during a visit to the United States and Britain in 1954. I owe an especial debt to Prof. Hawkins, Dr. Stephenson, Dr. Reeside, and Dr. Cox, who have read this paper in draft and made many valuable suggestions. Finally I owe thanks to my colleagues V. A. Zans and H. R. Versey for much help and encouragement and to Dr. S. H. Shaw and to the Directorate of Colonial Surveys for the preparation of the diagram (Text-fig. 1).

Previous Work

There has been considerable controversy as to the succession and correlation of the Jamaican Cretaceous rocks. Since the time of Etheridge (1869) it has been agreed by nearly all authors that only the upper Cretaceous is recognizable; from 1922 to 1926 most authors knew the correct succession of the limestones, especially that *Barrettia* was older than *Titanosarcolites* (Trechmann 1922a, Withers 1922, Hawkins 1923, Spath 1925); but since 1927 several have been under a misapprehension as to the sequence, the *Barrettia* beds being regarded as equivalent to, or even higher than the *Titanosarcolites* Limestone, and the *Veniella* Shales as older than either.

This change of view dates from the appearance of Trechmann's paper on the Cretaceous shales (1927). He had been the first to publish the correct Cretaceous succession (1922a, p. 423), and he had always held that all the limestones were of late age, either Maestrichtian (1922b) or Campanian-Maestrichtian (1924), whereas Hawkins, from his study of the echinoids (1923, 1924), thought that the *Barrettia* Limestone was Albian, the *Veniella* Shales Cenomanian, and the *Titanosarcolites* Limestone Turonian, or at latest Coniacian. In his 1927 paper Trechmann included not only all the limestones in the Maestrichtian, but also the *Diozoptyxis* Shale which he believed to be the highest formation present; he regarded the *Veniella* Shale as Campanian and the *Inoceramus* Shale as Middle Senonian. This correlation is obviously

inadmissable as it contradicts the sequence, but it led Douvillé to regard *Barrettia* as later than *Titanosarcolites*, the former being Maestrichtian and the latter Dordonian, and much confusion has arisen in subsequent literature.

To summarize—the *Inoceramus* Shales have been assigned to the Middle Senonian by Trechmann (1927); the *Barrettia* Limestone has been regarded as Albian by Hawkins (1923), as Turonian by Mullerried (1936), and as Maestrichtian by Trechmann (1927) and Douvillé (1927); the *Diozoptyxis* Shales were assigned to the Maestrichtian by Trechmann (1927); the *Veniella* Shales have been assigned to the Cenomanian by Hawkins (1923), and to the Campanian by Spath (1925), Trechmann (1927), and Withers (1927); the *Titanosarcolites* Limestone has been considered to be Turonian by Woolacott (Withers 1922) and by Hawkins (1924), to be Coniacian by Hawkins (1923), to be Dordonian by Douvillé (1927), and to be Maestrichtian by Trechmann (1927). Other elements of the *Titanosarcolites* fauna have been attributed to the Coniacian by Mullerried (1936), to the Campanian by Boissevain and MacGillavry (1932), and have been distributed through various stages from the Cenomanian to the Dordonian by Douvillé (1927). The *Ostrea* Limestone has been regarded as Maestrichtian by Trechmann (1924).

On the Alleged Association of Barrettia with Titanosarcolites

Many authors have followed Trechmann in treating *Barrettia* and *Titanosarcolites* as contemporaries, indeed it has almost come to be accepted as axiomatic. For example Stephenson (1938, p. 6), after noting that *T. giganteus* had been recorded in Jamaica, Cuba, St. Croix, and Chiapas, Mexico, added " on all the West Indian islands cited and in Chiapas, Mexico, *Titanosarcolites giganteus* is associated with *Barrettia* Woodward . . . ". This is a definite statement which requires investigation. If by " association " is meant occurrence on the same island, or in the same state, province, or parish, it is approximately true. If the generic name *Barrettia* is used to include *Praebarrettia sparcilirata*, the statement is true, as this species commonly occurs on the same horizon as *T. giganteus*. If the statement is intended to imply that *Barrettia monilifera*, *B. multilirata*, or any other species of *Barrettia* s.s. has been collected from the same horizon as *T. giganteus* anywhere in the Caribbean or Central American area, it is open to grave doubt.

Barrettia was first described by Woodward (1862) from the Rio Grande valley in eastern Jamaica, the type species being *B. monilifera*. Specimens referred to the same species were later described by Whitfield (1897b), together with two new species which he called *B. multilirata* and *B. sparcilirata*. *B. monilifera* and *B. multilirata* were stated to occur

together at Orange Cove in western Jamaica, whereas *B. sparcilirata* had been recognized only at Logie Green, near the centre of the island. Whitfield described other rudists (1897a), including *Caprinula gigantea* also known to him only from Logie Green. It is thought that the specimens described by Whitfield as *B. monilifera* should be regarded as a new species for which the name *B. gigas* has been proposed (Chubb, 1955). Trechmann restudied the *Barrettia* beds (1922b), and later he proposed (1924) two new generic names, *Titanosarcolites* for the species hitherto known as *Caprinula gigantea*, and *Praebarrettia* for the form previously called *Barrettia sparcilirata*. The forms referred by Trechmann to *B. monilifera* all belong to the new species *B. gigas*.

B. gigas was later found by Trechmann (1927, pp. 30–1) in a Cretaceous limestone in St. Ann's Great River Valley, St. Ann parish, and by Zans at Stapleton, near Newman's Hall, in the Sunderland Basin, St. James parish. *T. giganteus* is now known to occur not only at Logie Green, but at numerous other localities in Upper Clarendon, St. James, Westmoreland, and Portland. Up to the present, however, not a single specimen of *T. giganteus* has been found in the same limestone as *B. gigas*, *B. monilifera*, or *B. multilirata* anywhere in Jamaica, indeed the *T. giganteus* horizon is at least 2,500 feet higher than that containing *B. gigas* and *B. multilirata*.

The extra-Jamaican occurrences of *Barrettia* s.s., *Praebarrettia*, and *T. giganteus*, will now be considered. *Barrettia* and *Titanosarcolites* have wide and nearly co-extensive geographical ranges, approximately on the latitude of Jamaica, reaching from the state of Chiapas in southern Mexico to St. Croix in the Virgin Islands, a distance of about 2,000 miles. Northwards *Barrettia* ranges into Cuba, about 300 miles north of the latitude of Jamaica, and *Titansarcolites* to Central Texas, some 900 miles north of that latitude (Stephenson 1938).

The late Mr. J. T. Quin collected a number of fossils from St. Croix in the Virgin Islands (Vaughan 1923, p. 305) which were later found by Stanton to include among other species *Barrettia monilifera*, " *Barrettia* " *sparcilirata*, and " *Caprinula* " *gigantea*. There was no record as to whether *B. monilifera* came from the same horizon as *T. giganteus*, but an examination of the specimens in the U.S. National Museum brought to light an interesting fact. The specimens of *T. giganteus*, *P. sparcilirata*, *Acteonella sp.*, *Cerithium sp.*, *Glauconia sp.*, and *Astarte sp.*, are all more or less silicified, but none of the fourteen specimens of *B. monilifera* shows any trace of silification either of the shell, matrix, or infilling. It, therefore, seems probable that this species came from an horizon distinct from that of *T. giganteus* and that the latter was associated with *P. sparcilirata*, *Astarte*, and the gastropods.

Meyerhoff (1933, pp. 267–8) recorded the occurrence of *Barrettia* in

the Upper Cretaceous limestones of Puerto Rico. He did not mention *Titanosarcolites*. The American Museum of National History has about twenty specimens of *B. monilifera* from Magney Island near the south-west coast of Puerto Rico. No *Titanosarcolites* occurs with them. There seems to be no published record of the occurrence of *Barrettia*, *Praebarrettia*, or *Titanosarcolites* in the island of Hispaniola, which includes the republics of Dominica and Haiti, but the U.S. National Museum has two specimens of *Barrettia* from Haiti, of which one appears to be *B. monilifera* and the other *B. multilirata*. No specimens of *Titanosarcolites* were found with them.

The occurrence of *Barrettia* in Guatemala was reported by Sapper (1901) and by Dickerson and Weisbord (1931), who traced the rudist-bearing limestone into British Honduras. The species was identified by MacGillavry (1935, p. 558) as *B. monilifera*. None of these authors recorded the presence of *T. giganteus*. Mullerried (1934, pp. 81–2) reported the occurrence in Chiapas, Mexico, of a number of gigantic rudists including both *B. monilifera* (probably *B. gigas*) and *T. giganteus*. In a later paper (1936, pp. 38–9) he stated that *Barrettia* was accompanied by *Plagioptychus toucasi* and other pachydonts of the Turonian of Europe, but he did not list *T. giganteus* among its associates.

In Cuba, Thiadens reported (1936, pp. 1013, 1018; 1937, pp. 43–4) that "*Barrettia*" *sparcilirata* and *T. giganteus* had been found together in two localities in Southern Santa Clara province, but neither *B. monilifera* nor *B. multilirata* was recorded there. In Northern Santa Clara, on the other hand, both these species of *Barrettia* s.s. are present, according to Rutten (1936a and b), but not *T. giganteus*. MacGillavry (1937, pp. 89–90) lists the fossils found in association with *T. giganteus* in the province of Camaguey; they do not include *Barrettia*, although *B. monilifera* is found at other localities in the province (p. 125). Hermes's work confirms this (1945, p. 21). Vermunt (1937b, p. 263) gives a table showing the distribution of rudists in thirteen localities in the province of Pinar del Rio. *T. giganteus* is recorded from six localities and species of *Barrettia* from four. "*Barrettia*" *sparcilirata* occurs in association with *T. giganteus*, as in Jamaica, Southern Santa Clara, and elsewhere. There is one spot where *Barrettia* s.s., including both *B. monilifera* and *B. multilirata*, is reported to occur with *T. giganteus*, locality H.802, about 1½ km. south-west of San Diego. This unique occurrence would seem to require further investigation especially as in Vermunt's earlier study of the Province of Pinar del Rio (1937a, pp. 36–7) *T. giganteus* is not stated to occur at H.802, although both species of *Barrettia* are recorded there. One other record must be noted. Douvillé (1926, pp. 131–2) reported on a collection of fossils from l'Arroyo-Hondo, Camaguey, Cuba. In recording the occurrence of *T. giganteus* in association with *Barrettia* he seems to have relied on

the lithological resemblance of their matrix, and all that is actually known is that these two forms were found in the same river valley.

It would appear from this study that there are numerous reports of the occurrence of the four species *Titanosarcolites giganteus*, *Praebarrettia sparcilirata*, *Barrettia monilifera*, and *B. multilirata* in the Upper Cretaceous rocks of the Antilles and Central America, and that the first is commonly associated with the second, and the third with the fourth. Nevertheless there are very few reports of the association of *T. giganteus* or *Praebarrettia* with any species of *Barrettia* s.s., and those few are open to suspicion.

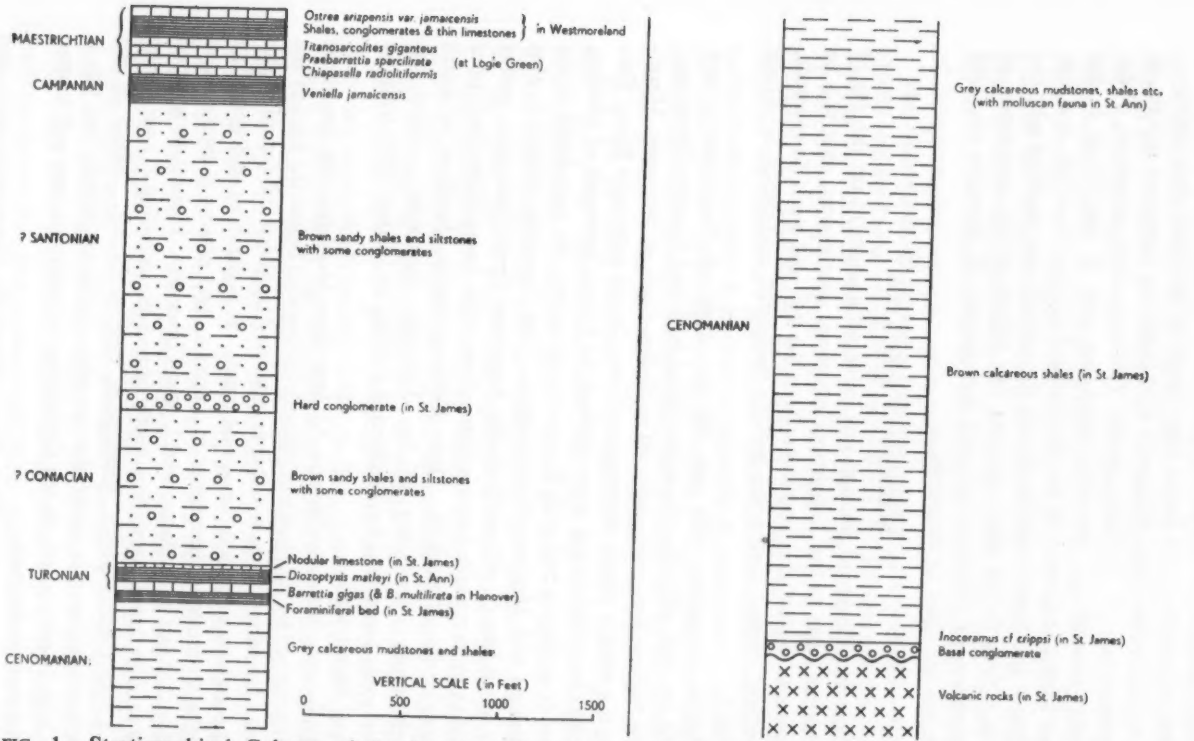
A Suggested Correlation

There is widespread, though not universal agreement on the age of the higher parts of the Jamaican Cretaceous succcession, so it will be convenient to start this discussion from the top, and work downwards. A vertical section giving the writer's suggested correlation is shown in Fig. 1.

Ostrea *Limestone*.—No one has yet disputed Trechmann's view (1924, pp. 387, 408) that the oyster which he found in some abundance, in the highest limestone about 40 to 50 feet thick, at Jerusalem Mountain, is a variety of the alectryonate form, *Ostrea arizpensis* Böse. This species characterizes the upper part of the Upper Senonian of Mexico, where it overlies a bed with *Exogyra costata* Say, the zone-fossil of the American and Mexican Maestrichtian. The Jamaican species is also very much like *O. falcata* from the American Upper Senonian, and it could even be regarded as a gerontic form of *O. lunata* from the Upper Maestrichtian of Norfolk. There seems no reason, therefore, to doubt Trechmann's correlation of the Jamaican oyster-bed, called the *Alectryonia* Limestone by Trechmann (1922a) and Hose (1950) with the Upper Maestrichtian.

Titanosarcolites *Limestone*.—At Jerusalem Mountain the limestone characterized by *T. giganteus* (Whitfield) lies well below the base of the *Ostrea* limestone, from which it is separated by about 100 feet of shales and conglomerates with limestone bands. It is the most widespread of all the Cretaceous limestones in Jamaica, and attains a thickness of 150 to 200 feet in St. James and Upper Clarendon. It contains a varied and prolific fauna, consisting chiefly of rudists, including *P. sparcilirata* at Logie Green, corals, gastropods, and echinoids. Many of the characteristic species occur also on other Antillean islands, but this is no help in correlation, as the Cretaceous succession is less well-known there than in Jamaica.

However, aid comes from Texas, where the Cretaceous fauna and succession are extremely well-known (Adkins 1928, Stephenson 1941). The fauna as a whole is quite distinct from that of Jamaica, in fact



TEXT-FIG. 1.—Stratigraphical Column of the Jamaican Cretaceous rocks, based chiefly on the succession in St. James Parish, with additional information from Westmoreland, Upper Clarendon, St. Ann, and Hanover.

none of the species characteristic of the *Titanosarcolites* Limestone is known to occur in Texas, but Stephenson (1938) found a rudist in the upper part of the Kemp clay (Maestrichtian), which he named *Titanosarcolites oddsensis*. An examination of the type in the U.S. National Museum showed that this species differs from *T. giganteus* in certain characters, but it is certain that the relationship of the two species is very close. This is strong presumptive evidence in favour of the Maestrichtian age of the Jamaican *Titanosarcolites* Limestone, which accords with the views of Trechmann (1924, 1927) and Douvillé (1927). It agrees too with the unpublished opinion of Stephenson (1942), for all the limestone fossils in the Matley collection which he listed and allocated to the Upper Campanian-Maestrichtian, were obviously derived from the *Titanosarcolites* Limestone.

Probably Woolacott (in Withers 1922) would not have wished his suggested attribution of a *Titanosarcolites* fauna to the Turonian to be taken too seriously. The views of Hawkins, however, cannot be lightly dismissed. From his study of the echinoids of the *Titanosarcolites* Limestone he drew the conclusion that the age of this formation is unlikely to be later than Lower Senonian (1923, pp. 212–13), and is probably Turonian (1924, p. 323). It would appear that the evidence furnished by the few echinoids conflicts with that provided by the abundant molluscs. One of Hawkins' species, *Heterosalenia occidentalis* (1923, pp. 206–213), belongs to a genus previously known by three species which occur respectively in the Rauracian, the Aptian, and at or a little above the top of the Turonian. He suggests that it may be a composite genus, including occasional orthogenetic offshoots from a persistent stock, such as *Hemicidaris*. This theory would seem to allow for the possibility of the new species being of more recent age than the others. Another species, *Botriopygus rudistarum* (1923, pp. 213–14), is less advanced than *B. alabamensis* of the Ripley formation (Lower Maestrichtian), suggesting an earlier age, but, as Hawkins points out, the possibility of the two forms being contemporaneous is not precluded. The third species, *Goniopygus supremus*, closely resembles *G. menardi* (Desm.) from the European Cenomanian. According to Douvillé, however (1927, p. 50) Lambert has noted the occurrence of a form analagous to *G. supremus* in the Campanian of Persia. In St. James *T. giganteus* appears to be confined to the uppermost part of a limestone 150 feet thick, so it is not improbable that the lower part may be Campanian in age, but in several localities specimens of *G. supremus* have been collected from the same exposures as *T. giganteus* in beds which the writer would definitely assign to the Maestrichtian.

Veniella *Shales*.—Between the *Titanosarcolites* and *Barrettia* Limestones there is in St. James a shale and conglomerate series some 2,500

feet thick. This series appears to be unfossiliferous through the greater part of its thickness, but the uppermost 150 feet, immediately below the base of the *Titanosarcolites* Limestone, are richly fossiliferous. These beds consist of purple, brown, and grey shales, siltstones, and indurated sandy beds, some of the shales being nodular or concretionary. It is on this horizon that we find the abundant *Veniella* fauna, which includes few if any rudists, but numerous normal lamellibranchs, among them the zone-fossil *Veniella* (*Roudaireia*) *jamaicensis* (Trechmann), with gastropods, some corals and a few other forms (see Trechmann, 1927). A comparison of this fauna with that of the Upper Cretaceous of North America (Adkins 1928, Stephenson 1941, Shimer and Shrock 1944) reveals that there are two species common to the two areas. The annelid, *Hamulus onyx* Morton, which occurs in the Eutaw formation (Coniacian) of Alabama, and in the Maestrichtian of Mexico, Texas, and other states, is abundant in some horizons of the *Veniella* Shales, and *Turritella trilira* Conrad, which in America ranges through the zones of *Exogyra ponderosa* and *E. costata* (Santonian-Maestrichtian) occurs in some localities. These two species indicate that the *Veniella* Shales represent some part of the Senonian.

The Providence shales (Trechmann 1927), which outcrop south of Port Antonio, Portland parish, near the eastern end of the island, closely resemble both faunally and lithologically the *Veniella* shales of St. James and Westmoreland and, though the zone-fossil has not yet been found in them, there can be little doubt that they are of the same age. Spath concluded (1925) from a study of the ammonites found in them by Trechmann, including species of *Epigoniceras*, *Parapachydiscus*, *Glyptoxeras*, and *Baculites*, that the Providence shales were of Campanian or even later age. Trechmann (1927) who compared the zone-fossil with *Veniella* (*Roudaireia*) *auressensis* (Coquand) of the Campanian of North Africa, agrees that the shales are Campanian, and Withers too (1927) is in accord. Matley's Cretaceous shale fossils from Upper Clarendon, most of which clearly belong to the *Veniella* fauna, though some may be more recent, were regarded by Stephenson (1942) as Upper Campanian or Maestrichtian in age.

In allocating the *Veniella* horizon to the Campanian the writer feels that he is in agreement with all the authors so far quoted, but unfortunately not with Hawkins. This author described (1923, pp. 205–6) indeterminable species of *Leiocidaris* and *Hemiaster* from these shales. He regarded the former species as closely comparable with *L. hemigranosus* from an approximately Cenomanian horizon in Texas, and the latter as suggesting affinity with Cenomanian or Turonian species of *Hemiaster* rather than any from higher horizons. He therefore favoured a Cenomanian age for the *Veniella* Shales, but the evidence was admittedly slim, as " *Leiocidaris* ranges from the Oxfordian to the

present day with remarkable specific constancy" (Hawkins, 1923, p. 205), while the range of Hemiaster is from Lower Cretaceous to Recent.

Diozoptyxis *Shales.*—As noted above, in St. James the *Veniella* fauna occurs in the uppermost part of a shale and conglomerate series at least 2,500 feet thick, so if this fauna is Campanian, the middle and lower parts of the series may well include representatives of the Santonian, Coniacian, and even Turonian. In this connection it is of great interest that Trechmann found (1927, pp. 30–1), in St. Ann's Great River Valley, immediately above the *Barrettia* Limestone, a fossiliferous formation about 40 feet thick, consisting of grey and black shales becoming calcareous towards the base. These shales, which are here called the *Diozoptyxis* Shales, are succeeded by a considerable thickness of conglomerates and shales, believed by Trechmann to be Lower Eocene, but more probably Cretaceous, and corresponding to the thick succession of unfossiliferous conglomerates and shales which in St. James intervene between the *Barrettia* Limestone and the *Veniella* Shales. Indeed, the recent discovery of Maestrichtian rudists in the river-gravels suggests that the *Titanosarcolites* Limestone is present above this series, though no exposures have been found as yet. Trechmann listed fifteen species from the *Diozoptyxis* Shales, and the interesting point is that not one of these species is found in the shales below the *Barrettia* Limestone, and only two are found in the *Veniella* Shales, *Pholadomya jamaicensis* Trechmann, and the ubiquitous *Neithea quadricostata* Sow., which occurs also in the *Barrettia* Limestone. It would appear then that these shales constitute a distinct and recognizable palaeontological horizon, which is here named after its most characteristic fossil *Diozoptyxis* (*Glauconia*) *matleyi* (Trechmann).

Trechmann, holding the view that " the *Barrettia* and other Rudist Limestones are certainly very high Senonian if not Maestrichtian " (1927, p. 63), naturally concluded that " the shales above the limestone at St. Ann's Great River (*Diozoptyxis* Shales) are still later in age ". In view of the fact that these shales lie at least 2,300 feet below the horizon of the *Veniella* Shales, which Trechmann himself admits to be Campanian, it is impossible to accept a late Maestrichtian age for these beds. Trechmann stressed the fact that a few of the gastropods could be compared with forms from the highest Cretaceous of the Libyan desert and India, but perhaps more significance should be attached to the resemblance of *Diozoptyxis matleyi* to species from Gosau, which Cossmann placed in the Turonian. *Neithea quadricostata* is characteristic of the Upper Greensand (Albian-Cenomanian) of England, but similar forms from higher horizons should probably not be identified with it; *Pholadomya jamaicensis* is compared by Trechmann to *P. vignesi* Lartet from the Cenomanian and Turonian of Palestine,

Socotra, and Zululand, and a species of *Plicatula* resembles *P. andersoni* Newton, also from Zululand. Another *Plicatula* resembles *P. urticosa* Morton from the Raritan green marls (Cenomanian) of New Jersey. A species of *Cytherea* resembles *C. plana* from the Rostrata zone of the Upper Greensand (Albian). *Amusium membranaceum* Nilsson has a longer range, extending through the Middle and Upper Cretaceous of Sweden, Hanover, and Maestricht, and characterizing also the Arrialoor beds (Senonian) of southern India.

On the basis of this evidence, much of it culled from Trechmann's paper (1927) it would appear probable that the age of the *Diozoptyxis* Shales is Turonian. There appears to be little evidence for a later age, and an earlier age would seem to be unlikely as the underlying formation is also regarded as Turonian.

Barrettia *Limestone*.—This limestone, which varies in thickness from 15 to 25 feet is characterized by *B. gigas*, associated with *B. multilirata* at Green Island, but not with *Praebarrettia sparcilirata*. Clearly it cannot be Maestrichtian as believed by Trechmann, Douvillé, and others, as in the Sunderland Basin it is about 2,400 feet below the *Veniella* Shales (Campanian). One of Trechmann's arguments in favour of a Maestrichtian age for all the Jamaican Cretaceous limestones was the supposed absence of ligament-bearing genera of both the Radiolitinae and the Biradiolitinae for, according to Douvillé, among Old World faunas, the former group lost their ligaments in the Dordonian and most species of the latter group lost theirs in the Turonian. In the course of the present survey several ligament-bearing forms have been found. A species of the radiolitine *Praeradiolites* seems to be fairly common in the *Barrettia* Limestone at Stapleton and a single specimen of a species of the biradiolitine *Sauvagesia* has also been found there. This evidence would seem to favour an age not later than the Turonian for this limestone, which accords with the view of Dickerson and Weisbord (1931) who believed the horizon of the Guatemalan *Barrettia* to be " middle Upper Cretaceous ".

Confirmation of this view comes from the state of Chiapas, Mexico, where Mullerried found (1926), above the *Barrettia* series, two ammonite horizons, the lower containing the Upper Turonian forms *Lytoceras* (*Gaudryceras*) sp., *Pachydiscus peramplus* var. *beyrensis* Choffat, and *Acanthoceras* sp., and the upper yielding the Lower Senonian genus *Hauericeras*. Mullerried therefore concluded that *Barrettia* pertains to the Upper Turonian, and he found it to be associated with *Plagioptychus toucasi* Matheron and other rudists characteristic of the Turonian of Europe.

This observation conflicts with that of M. G. Rutten (1936a) who reported that in Northern Santa Clara province, Cuba, Turonian ammonites occur below the *Barrettia* horizon. Here the Habana forma-

tion, yielding *B. monilifera* and *B. multilirata* is said to rest unconformably upon a tuff series, with intercalated limestones, containing the ammonites *Austiniceras dibleyi* Spath, *Pachydiscus* sp., *Peroniceras cochii* Meneghini, *Peroniceras* spp., *Barroisiceras* sp., and *Crioceras* sp., which, like the forms found by Mullerried in Mexico, indicate a Turonian Coniacian age. In this connection MacGillavry observes (1937, p. 12) " if the Ammonite-faunae in Mexico and Cuba are really of the same age, and if the Ammonite-bearing strata in Cuba are really intercalated in the Tuff Series, then we must assume the existence of a tectonical complication in the Chiapas profile." Surely we would be equally justified in assuming such a complication in the Santa Clara profile. It may be noted too that MacGillavry's words seem to suggest a doubt as to whether the ammonite beds in Cuba are really intercalated in the Tuff Series. It is easy to understand a failure to observe a tectonic complication, a doubt as to a stratigraphic succession, or even the mixing of fossils from different localities, if the circumstances in which these observations were made are taken into consideration. M. G. Rutten and H. J. MacGillavry with L. W. J. Vermunt and A. A. Thiadens were members of a party of students from Utrecht University who, under the leadership of the late Prof. L. M. R. Rutten, set out in 1933 to explore the geology of Cuba. Two months were devoted to a survey of the province of Santa Clara, an area of approximately 15,000 sq. km. A prodigious amount of valuable work was accomplished, but it is evident that the survey can have been only a rapid and rather superficial reconnaissance.

Actually Prof. Rutten's former students do not agree as to the age of the Tuff Series of Cuba, MacGillavry regarding it as Albian (1937, pp. 10–12), Thiadens as Cenomanian-Turonian (1936b, pp. 1132–3), and M. G. Rutten (1936a, p. 36) as Lower Cretaceous to Emscherian. Van Wessem (1943, p. 8) who accompanied a second party to Cuba in 1938–9, found *P. sparcilirata* in the series, which he regarded as Lower Senonian. However, as another member of the second party, J. J. Hermes, points out (1945, p. 5), the presence of this species would mean a Maestrichtian age. Hermes is not satisfied (1945, p. 9) with MacGillavry's attempt to discredit the occurrence of *Barrettia* below a Turonian ammonite horizon in Chiapas. He thinks this genus already lived in Middle Cretaceous times. According to a table published by a third member of this group, F. G. Keijzer (1945, p. 152), the fossils indicate that the Tuff Series ranges from the Barremian to the Danian, and the Habana Formation from the Albian to the Danian. This does not bear out the view that the latter formation overlies the former unconformably, though no doubt unconformities are present. Probably the so-called " Tuff Series " of Cuba is an indefinite lithological term analogous with Sawkins's " Trappean Series " in Jamaica, which

embraced all the tuffaceous, conglomeratic, arenaceous and argillaceous rocks in the Cretaceous succession. It included the series here called the *Inoceramus*, *Diozoptyxis*, and *Veniella* Shales, as well as the unfossiliferous beds of similar lithology. The three Cretaceous limestones are intercalated in the Trappean Series, and in Upper Clarendon there is at least one unconformity.

Hawkins (1923, pp. 203–5), on the basis of a single specimen of a new species of a new genus of echinoid, *Metholectypus trechmanni*, inclines to the view that the *Barrettia* beds are Albian. The grounds for this suggestion are that *M. trechmanni* resembles *Lanieria*, from a horizon in Cuba regarded as Cretaceous, and the only other member of the family to which *Lanieria* belongs is *Dischолectypus*, an Albian genus. He adds " I have no intention of stating a definite belief that the *Barrettia* beds of Jamaica . . . must of necessity occupy so low a place in the Cretaceous sequence ". The Geological Survey has recently found two poorly preserved echinoids in the *Barrettia* Limestone, which were provisionally determined by Prof. Hawkins, during his recent visit, as *Macraster* sp. and *Heteraster* sp. In Texas both these are typically Albian genera, though the latter extends up into the Upper Buda formation, which many authors regard as Cenomanian. It would appear that throughout Upper Cretaceous times Jamaica was a home of retirement for elderly echinoid genera which had found the struggle for survival too severe in other less favoured parts of the world.

Taking all factors into consideration, and in spite of some evidence for an earlier age, it seems probable that the *Barrettia* Limestone should be regarded as Turonian.

Inoceramus *Series*.—Immediately below the *Barrettia* Limestone at Stapleton there is a light brown mudstone, six or eight feet thick yielding foraminifera, echinoids, and lamellibranchs. The fossils are in the form of moulds or impressions, and it is not yet known whether it will be possible to recognize in this bed another palaeontological horizon.

This is underlain by a considerable series of shales, mudstones, and shaley sandstones with a basal conglomerate. The thickness appears to be between 4,000 and 5,000 feet and the deposits are mainly hard grey mudstones in the upper part, passing down into brown laminated shales below, with the basal conglomerate, seen north of Sunderland, resting on volcanic rocks. In St. Ann's Great River Valley the sub-*Barrettia* shales and conglomerates were estimated by Trechmann to be about 1,400 feet thick, but this is probably an under-estimate, the true thickness being about 2,500 feet. Here the base is not seen and the deposits, which consist of grey and blackish shales, shaley sandstones often containing small scattered black pebbles, and conglomerates, probably correspond with only the upper part of the series in the Sunderland inlier. Most of the deposits are distinctly calcareous,

in contradistinction to the shales between the *Barrettia* and *Titanosarcolites* limestones which are generally only very slightly so, or are non-calcareous.

Trechmann described (1927) eight species of molluscs from an horizon in the shales, believed by him to be 800 to 1,000 feet below the *Barrettia* Limestone, in St. Ann's Great River valley, to which number the Geological Survey has added several others. None of these species are found in any higher horizons. Trechmann compares some of his species with Senonian forms, but considering the low stratigraphic position of this series the resemblances are probably superficial, and most of the newly-discovered species show affinities rather with those of the Cenomanian or even Upper Albian. Among Trechmann's fossils was a specimen of *Inoceramus* collected by Messrs. J. V. Harrison and P. T. Cox, who at that time (April 1925) were carrying out an investigation into the oil possibilities of the area. Trechmann described this (1927, p. 52) as very near if not identical with *I. balticus* Böhm, a Senonian species, which in England, Europe, and North Africa ranges from the Santonian to the Maestrichtian. A very similar specimen, picked up by Hawkins during his recent visit, shows the abrupt change of slope characteristic of *I. inconstans* Woods (Turonian-Senonian). Like the Harrison and Cox specimen, this is preserved as a calcareous glauconitic concretion, and it was found as a loose pebble in the river-bed where it is cut in strata well below the *Barrettia* Limestone. The specimen, however, is somewhat water-worn, and there can be little doubt that it has been brought down from higher upstream, possibly from above the *Barrettia* horizon.

Other *Inoceramus*, many of them small, or when larger fragmentary, are found *in situ* in the lower beds of the St. Ann's Great River section, associated with the molluscan fauna described by Trechmann. These appear to belong to a different species, resembling *I. crippsi* Mantell.

In the lowest shales of the Sunderland basin, immediately above the basal conglomerate, and probably over 4,000 feet below the *Barrettia* Limestone of Stapleton, a large species of *Inoceramus* is fairly common. A lithologically-similar shale series in the lower part of the Cretaceous at Peters Hill, in the Central Inlier of Upper Clarendon, yields a similar form, and nearby at Style Bottom there is a gastropod fauna resembling that of St. Ann's Great River. The *Inoceramus* shells attain a diameter of 200 mm. or more, and it is noticeable that they do not show the extreme convexity and increase of length relatively to height that characterize *I. balticus* in old age (Woods, 1912, p. 295, fig. 53), indeed the length is generally slightly less than the height. In these characters, as well as in its general appearance and ornament, it more closely resembles *I. crippsi*, which has been regarded by some authors as synonymous with *I. balticus*. It is, however, an earlier species, in

England ranging through the Cenomanian from the *Pecten asper* beds to the *Holaster subglobosus* zone (Woods 1912, pp. 276–8) and occurring at the same horizon in various European localities.

Considering the resemblance of the common Jamaica species to Cenomanian forms, and its low stratigraphic horizon, in places as much as 4,000 feet or more below the Turonian *Barrettia* Limestone, it may be reasonably inferred that the *Inoceramus* Shales should be regarded as Cenomanian in age. Until the discovery of more perfect specimens makes an exact determination possible, it is preferable to call the common species *Inoceramus* cf. *crippsi* rather than to adopt Trechmann's name of *I.* cf. *balticus*.

During a recent visit to Cuba, Zans observed a formation that is probably equivalent to the *Inoceramus* Shale of Jamaica. He made a traverse from Santa Clara southward through Seibabo and Matagua to Manicaragua and beyond. He found *Barrettia* sp. at Seibabo in the basal beds of the limestone mapped by M. G. Rutten as the Habana Formation. Thence the road passes over the underlying Tuff Series, for a distance of about 7 km. He observed that south of Matagua this series contains, interstratified with tuffs, many beds of shale which show close lithological resemblance to the *Inoceramus* Shale, and he has little doubt that in this locality it is of the same age, though he had insufficient time to hunt for fossils.

Conclusions

The probable reason for the widely held view that the Cretaceous rocks of Jamaica are all of Upper Senonian age is that the *Veniella* Shale and the *Titanosarcolites* Limestone, which actually do belong to this epoch, are profusely fossiliferous and outcrop over very extensive areas. All Matley's fossils from Upper Clarendon, numbering about 160 species, were certainly derived from these horizons and were quite correctly attributed by Stephenson to the Upper Campanian and Maestrichtian. But it may be pointed out that these formations, together with the *Ostrea* Limestone, represent a total thickness of no more than 500 feet.

The underlying Cretaceous rocks attain a thickness of about 7,000 feet, and except in certain bands this group is generally unfossiliferous. A total of little more than 30 species have been listed by Trechmann from the few fossiliferous beds in this great succession, and apart from the rudists in the *Barrettia* Limestone these are mostly small and inconspicuous shale mollusca, few of which have even been named.

In this paper arguments have been brought forward, based on the fossil evidence and stratigraphic succession in Jamaica, backed by evidence from other Caribbean islands, from Central America, Texas, and elsewhere, that the lowest fossiliferous horizon in Jamaica, the

Inoceramus Shale, is of Cenomanian age, the *Barrettia* Limestone and *Diozoptyxis* Shale are Turonian, the *Veniella* Shale is Campanian, and the *Titanosarcolites* and *Ostrea* Limestones are Maestrichtian.

It would appear that the genus *Barrettia* s.s. ranges through a greater thickness of limestone in Cuba than in Jamaica, though there and in all other areas it probably became extinct before the advent of *Titanosarcolites*.

After this paper had been completed a report was received from Dr. P. Bronniman of the Cuban Gulf Oil Company, Havana, on a series of specimens of rock-material from different horizons in the Jamaican Cretaceous, which had been submitted to him for study of their foraminifera. Nearly all his age-determinations differ from those suggested above. Of seven specimens of the *Inoceramus* Series one is attributed to High Cenomanian-Lower Turonian, most of the others fall in the range Turonian-Maestrichtian, and one sample is said to contain Turonian-Campanian and Recent foraminifera mixed. The brown mudstone below *Barrettia* is described as Upper Cretaceous or Middle Eocene, and the *Barrettia* Limestone itself as Campanian or Maestrichtian. Four specimens of the *Veniella* Shale from different localities are all stated to be of Middle Eocene age, while the overlying *Titanosarcolites* Limestone reverts to the Campanian or Maestrichlian. Dr. Bronnimann has since found that *Eponides jamaicensis* Cushman and Jarvis, on which he based his Middle Eocene determination of the *Veniella* Shale is a synonym of *Lockhartia bermudezi* Cole from the Habana formation of Cuba. It appears therefore that there is no doubt as to the Upper Cretaceous age of these shales.

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GEOLOGICAL SURVEY DEPARTMENT,
KINGSTON,
JAMAICA, B.W.I.

Wegener's South America–Africa Assembly, Fit or Misfit?

By S. Warren Carey

(PLATE IX)

ABSTRACT

A statement by Jeffreys that the Wegener fit of South America and Africa is a misfit of 15° has been widely quoted and accepted. However, careful check by any rigorous method will show that these continents do in fact fit together as precisely as their forms can be defined. Whether continental drift be true or false, this argument against it must be abandoned.

THE South America-Africa apposition has been adopted, with variations only of spacing, by every proponent of continental drift. However, with regard to the alleged fit of South America into the angle of Africa, Jeffreys (1929, p. 322) has objected that " on a moment's examination of the globe this is seen to be really a misfit by almost 15°. The coasts along the arms could not be brought within hundreds of kilometers of each other without distortion. The widths of the shallow margins of the oceans lend no support to the idea that the forms have been greatly altered by denudation and deposition ". I and others have been aware for a long time that this argument is invalid, but considered that this would be generally realized, and that the criticism would die out. But Jeffreys has repeated the statement in the second edition of his book (1952, p. 349), and Lees (1953, p. 234) has listed this as one of his three serious objections to the drift hypothesis. It is therefore necessary to correct this error formally. For if continental drift should be rejected, let it be rejected only on valid grounds.

Techniques of Comparative Morphology on a Global Scale

The comparison of two long coasts or other irregular forms on the earth's surface is not such a straightforward procedure as might be imagined. No projection can be used directly because of the differential distortion caused by translation and rotation with respect to the axes of the projection, and comparison on a globe is not so easy as it might appear. I had a 30 in. globe specially made for this purpose with the 100 fathom and 1,000 fathom lines as colour boundaries. Even this was found to be too inaccurate for any but rough morphological comparisons since, like all commercial globes, the base map was first printed in gores, themselves plane projections, and stretched on to the globe.

Lest there should be any doubt about the validity of the methods, and also because it should make it easier for others who would make such comparisons, it is necessary to describe in some detail the methods which I have developed for such global morphological studies.

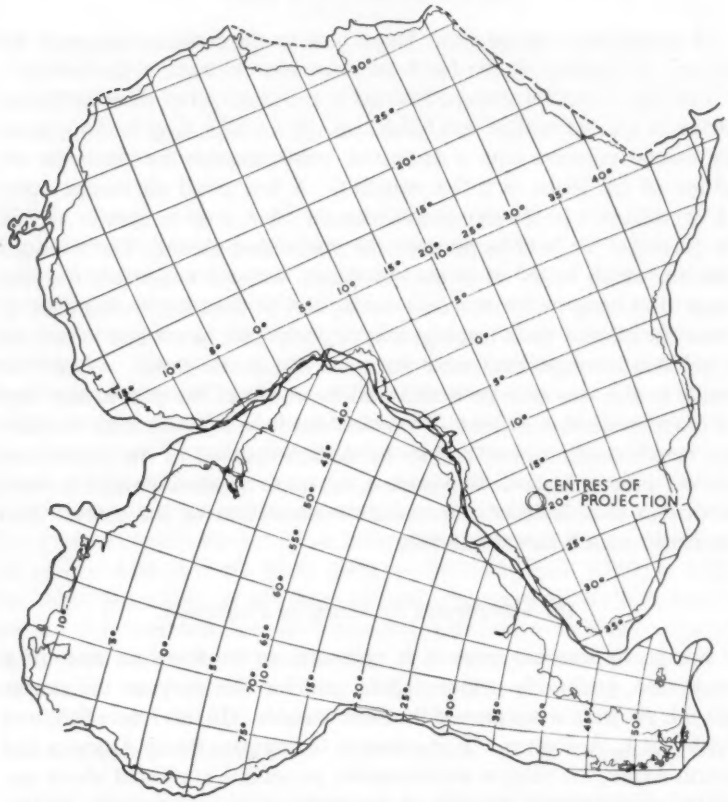
(*a*) *Comparison on a Globe*

A mould was turned from Huon pine to the same curvature as the globe. A tracing plastic (such as polyvinyl chloride, " Kodatrace ", " Ethulon ", etc.) is stretched across it and waterproof sides with inset strips of sponge rubber, are bolted on. Hot water, near boiling, aided by careful pressure with a drumstick swab, moulds the plastic to the shape of the globe in a few minutes. A few small air escape holes $\frac{1}{16}$ in. diameter in the mould are necessary, but even so care is needed to get rid of air bubbles between the plastic and mould. The moulded plastic, which holds its shape excellently without noticeable warping even after lying by for several months, can be used for tracing directly from the globe ; these tracings may be compared, or cut and joined, on a gridded hemispherical table the same size as the globe. Assemblies made in this way may be transferred by means of the grid to any type of plane projection desired. The writer has found this method excellent for rough work, limited mainly by the inaccuracies of the globe itself (errors were as much as 30 minutes), but quite accurate enough to make it certain that Jeffreys' " moment's examination of the globe " had seriously misled him (Plate IX).

(*b*) *Comparison by Means of Projection*

For more accurate work it is necessary to work on an azimuthal projection, preferably orthomorphic, and for this purpose the stereographic projection has proved the most suitable. (In this I have followed Professor L. A. Cotton.) For example, to compare South America and South Africa, an oblique stereographic projection is plotted about any centre convenient to the part of the globe to be investigated. In this case 19° S. 19° E. was arbitrarily chosen for South Africa. Now if South America were placed in position in the angle of Africa, this centre of projection would fall at a quite different place on the South American grid—at 32° S. 42½° W. in fact. So a separate oblique stereographic projection is plotted about this centre and the South American coast and shelf is plotted on it. If these two projections are now superimposed so that the centres of projection coincide, a direct and accurate comparison of the shapes of the coasts may be made (Text-fig. 1). For though distortion is present in each figure, such distortion is with respect to the centre of projection, and so long as the

centres of projection coincide, curves which are similar on the projection are also similar on the globe. Text-fig. 1 shows the degree of similarity which in fact exists between the shapes of Africa and South America, if we make the comparison at the 2,000 m. line (half-way down the continental slope).



TEXT-FIG. 1.—Africa and South America compared at the 2,000-m. isobath. Overlaps occur at Niger delta and at roots of submarine ridges.

An overlap occurs at the Niger delta (which has grown there more recently than any alleged fit) and smaller projections overlap at the points where the narrow Walvis and Martin Vaz ridges leave the coasts.

If a mean line is drawn between the two matched isobaths, the departure of either from the mean is usually much less than half a degree of arc. This is the limit of definition of the shapes involved.

This is true along an arc distance of 45 from the angle at the Cameroons. The angular misfit is therefore zero plus or minus forty minutes. It is very doubtful whether the bathymetric data warrant a measurement as precise as this. Suffice it to state that no measurable misfit has been detected.

The diagrams constructed do not express opinions, or theories but objective facts, which may be verified by anyone who cares to take the pains to do so. Jeffreys' statement that there is a 15° misfit is therefore untrue. Whether the continental drift hypothesis be true or false, this argument should never be used against it again. In fact the reverse is true, since the probability of the degree of morphological coincidence, revealed by Text-fig. 1, being pure chance must be low, and is reduced substantially further when objective structural and stratigraphic similarities are simultaneously taken into account.

Other graphical methods of comparison of coasts, such as translation along great circle arcs and rotation along small circle arcs on a stereographic projection, have been tried but, although this method is theoretically sound, inaccuracies accumulate due to magnification of plotting errors. The method described above for the comparison of Africa and South America, has been found to be the most satisfactory and can be made as accurate as may be desired by drawing closer grids on larger scales of base circle, and using more refined source material.

Which isobath should be used in comparing such coasts? All will agree without argument that the present coast should be rejected and that some level on the slope from the continental shelf would give a more significant comparison. Examination of the problem shows that the 2,000 m. isobath is the logical boundary. The mean level of the ocean floors is a little more than 4,000 m. below sea level and the mean level of continental plateaus is a little above sea-level. The 2,000 m. isobath is therefore a close approximation to half the " freeboard " of the continental rafts above the sea floor.

This is significant to the relation of the Mid-Atlantic Ridge to the fitting of these coasts. For this ridge does not show up until the 3,000 m. and deeper isobaths are drawn. Only a few small islands project above the 2,000 m. line. Although the position and pattern of this ridge may have considerable significance, its width has no significance whatever in comparing the forms of the African and South American continents.

ACKNOWLDGEMENT

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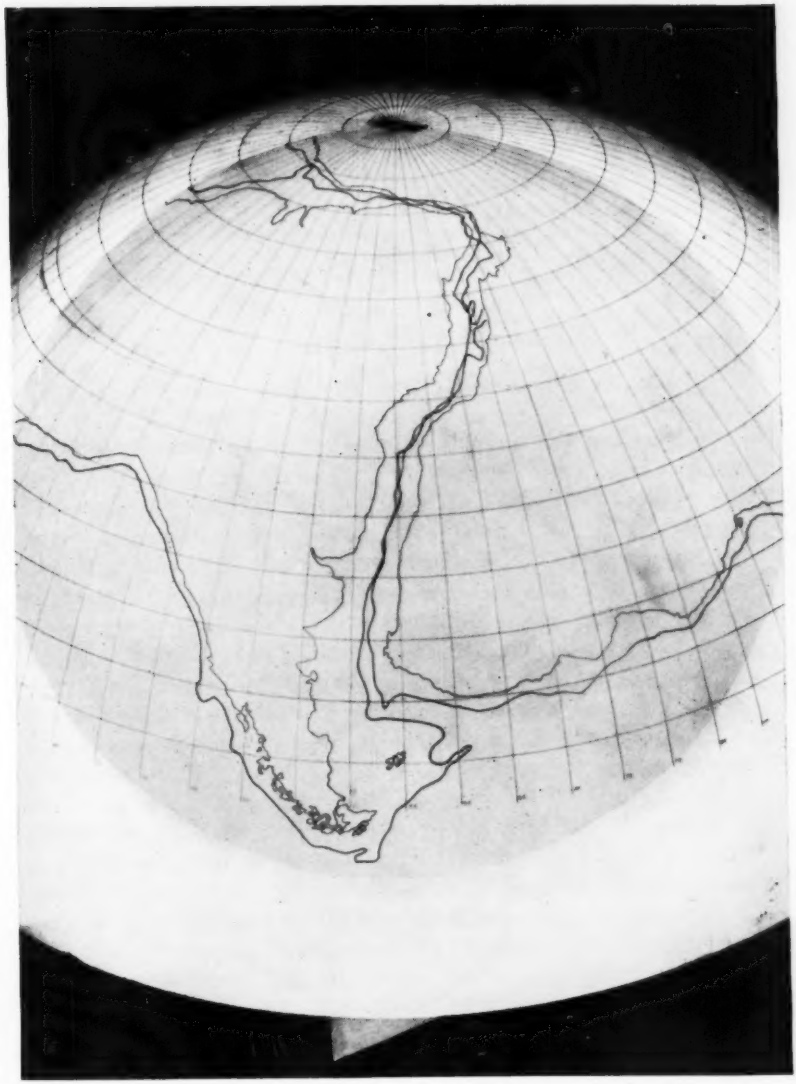
GEOLOGY DEPARTMENT,
UNIVERSITY OF TASMANIA.
HOBART.

EXPLANATION OF PLATE IX

Close-up of photograph of tracing on spherical table showing fit of South America and Africa at 2,000-m. line. The grid is on the table not the tracing, and hence has no relation to the grid of either continent. However, it is a 5° grid and can be used for measuring arc distances on the photograph.



MOULDED PLASTIC TRACING ON SPHERICAL TABLE.

Wealden Plant Microfossils

By N. F. HUGHES

(PLATES X–XII)

ABSTRACT

One new and several re-interpreted species of Lower Cretaceous age are included in *Pyrobolospora*, a new organ-genus of large spores bearing neck structures; in *Triletes* (section *Aphanozonati*) are placed two other species of megaspores, one emended and one new. These are a small part of a distinctive Wealden assemblage of plant microfossils, which represents a critical period in plant evolution and which should play its part in stratigraphy. Certain difficulties in nomenclature and morphology are discussed.

I. INTRODUCTION

A STUDY which is in progress of the plant microfossils of the English Wealden beds, has inspired the hope that they may prove to be of some use in correlating the various scattered outcrop successions, with the Continental "Wealden" and thus eventually with marine equivalents both in England and abroad. It will be easier, however, to make use of this plant evidence when the ostracod zones of Anderson (1939 and 1940) become available. The plant material is plentiful and is mostly collected from beds containing few ostracods or other fossils; the two lines of evidence should thus be complementary. The assembling of plant evidence on the scale of ostracod information already obtained will take some time and it is not expected to result in the erection of any scheme of purely floral zones. The problem of the age of the various parts of the Wealden series in England has not been solved over a long period, and there is little chance of this being done even now by one research method alone. It is of course necessary to attempt zonation, but this is bound to be artificial and "strained" if based on one fossil group; pointers must be sought to the natural overall pattern or direction of geological change which it is believed may be determinable from these sequences and areas, when all the evidence is considered together. Working from the basis of the sedimentary evidence of Allen (1954 and earlier), with the addition of ostracod, plant, and all other fossil information, the effect of the general pattern of geological evolution of the area should become apparent.

The best chance of finding a solution in this case is believed to lie in such a close integration of the simultaneous effort of several individuals. The present paper is concerned solely with some preliminary descriptions.

Plant Fossils and Geology

The use of plant-fossils in the stratigraphy of the Carboniferous system has an unfortunate history (Jongmans, 1952), and little has been attempted in later systems. Although there can be no comparison with the general usefulness of graptolites and cephalopods in zoning, transported plant microfossils are no worse material than many other animal groups which have had to be used ; in fact such plants which have floated even for a short time may well be more widely distributed than some benthonic organisms.

The rigid higher-group framework in botanical classification of living plants which has of necessity been used for fossil plants, has had the effect of support for the idea of plant evolution being too slow to be of stratigraphical use ; this is illustrated by several contemporary botanical textbooks, which infer that a cryptogenetic group such as the Angiosperms must have had a long undetected history, in order to achieve its high state of perfection on appearance. This view of plant evolution is thought to be misleading and it is suggested that judgment on this problem be withheld.

II. The Wealden Flora

Seward (1894–5, 1913) described the macrofossils and little has since been added, but his specimens came almost entirely from the Fairlight Clays at the base of the series. The larger plant microfossils, which come from nearly all horizons of the Wealden include megaspores, seeds and similar bodies, and cuticles of various plant organs. The complementary study of British Wealden microspores and pollens has only recently begun, although a very brief survey of German Infra-Valanginian Wealden is given by Thiergart (1949).

Twenty of the twenty-six Wealden megaspore species described from Dutch borings and from Kingsclere by Dijkstra (1951) are now recorded from outcrop sections mainly on the South Coast of England. This includes nine which were only previously known from Holland and there are in addition a number of new forms.

III. Collection of Material

Megaspores are sometimes very common, occasionally reaching hundreds in a 2 oz. sample ; they are however seldom discernable in the field. It has not yet proved possible to pick out with certainty a megaspore-bearing bed, although many sediments can be rejected. The best lithology is a silt, which is frequently commoner than true clay both in the Hastings Beds and the Isle of Wight Wealden Marls ; there should be small plant fragments visible, but these should not be merely pieces of charcoal or be heavily pyritized. If plant fragments

(pieces of stems and leaves) are large and abundant, there are usually few spores ; this is presumably due to difference in transportability. Dijkstra (1949, p. 21) pointed out that poor sorting in the sediment increased the chance of survival of plant material, but conditions inferred from poor sorting may also have favoured deposition of this kind of fossil.

Laboratory Treatment

The object is separation and cleaning with a minimum of further destruction. The most tedious operation is that of picking out spores, seeds, etc., individually from the mass of largely unrecognizable plant debris, as no flotation separation is of course possible ; this is most easily done under water, with a low-power binocular.

An adequate average sample is about 50 gms., but this should be decreased if plant material is obviously plentiful and vice versa. The sample is dropped into boiling water to which has been added a small amount (about 3 gms.) of anhydrous sodium carbonate which produces a slow release of carbon dioxide on continued boiling. If the rock is not broken down in 15 minutes, the material should be dried and the process repeated at least once. Dijkstra (1951) describing this process recommended retaining the material on a sieve of mesh size 0·1 mm. and examining when dry ; it has been found easier to use three sieves of 40, 80, and 100 meshes to the inch and to examine the results from each sieve separately under water with a stereoscopic binocular of 20–30 × magnification. Most megaspores apart from a few large ones are held by the 80 sieve and practically none appear on the 100 sieve (approximately 150μ mesh) which is used merely as a check for the few very small types known, such as *Triletes adoxus* Dijkstra. Spores with any kind of appendages must usually be cleaned with hydrofluoric acid after isolation, particularly if they are to be drawn, photographed, sectioned, or dissected.

IV. Systematic Section

A. Discussion of Genera

Dijkstra (1951) classified Wealden megaspores under three sections of the Genus *Triletes* Reinsch emend. Schopf—*Aphanozonati*, *Zonales*, and *Lagenicula*, only the last of which is fully discussed in this paper. It is intended here to separate from *Triletes* a new group, *Pyrobolospora*, which will include a new species and several species from the *Lagenicula* section. From a morphographic point of view, none of the Lower Cretaceous species can now belong to the sub-division *Lagenotriletes* or to the genus *Lagenicula* within it as redefined by Potonié and Kremp (1954), although one Upper Cretaceous species could possibly be still included. *Lagenicula* as now restricted requires the characters : polar

axis usually greater than equatorial, contact faces well developed, emergences from exine short spines but never blunt appendages. Potonié in addition makes a good case for regarding the *Lagenotriletes* group as megaspores only of the *Lepidodendraceae* and *Bothrodendraceae* excluding even the *Sigillariaceae* (also Chaloner 1953 and 1954) ; this would seem to be a further reason for erecting a new organ-genus to receive these Cretaceous " megaspores ", which have not yet been reported from the Jurassic or the Tertiary.

B. Division (Oberabteilung) Sporites H. Potonié.

Organ-genus *Pyrobolospora* gen. nov.

Diagnosis.—Spores in the megaspore size-range (150μ upwards) with a prominent neck composed of (usually) six segments. Spore-body spherical (and not axially elongated), covered uniformly by sculptine detail which may vary in different species from small granules to appendages 300μ long. Inner spore-wall (intexine) is much thinner and darker coloured than the exoexine. Small tri-radiate tetrad scar is present apically beneath the neck and may only be seen by dissection or in microtome sections.

Type Species.—Pyrobolospora vectis gen. et sp. nov.

Derivation of name.—Gr. πυρόβολος—giving forth fire ; of a grenade or bomb.

Comment.—This name is given in order to separate what is believed to be a homogeneous group from previous confusing attributions. The genus is not placed in the Division (Abteilung)—*Triletes* of Potonié and Kremp, although it may eventually be included there.

Pyrobolospora vectis gen. et sp. nov.

Plate X, figs. 1–3 ; Plate XI, fig. 6 ; Plate XII, figs. 3–8, 10–11 ; Text-fig. 1, 2

Abstract Diagnosis.—Small (200–300μ) dark thick-walled megaspore with a prominent neck and with the body covered by numerous very long (150–200μ) translucent appendages arising from low ridges (Plate X, fig. 1).

Type Preparations.—S.M. K2229–46.

Locality and Horizon.—Cliff opposite remains of Yaverland sea-wall, N.E. of Sandown, Isle of Wight ; locality S 18. Approximately 30 feet below top of Wealden Marls (Osborne White, 1921, p. 19).

Description.—Spore-body roughly spherical ; equatorial diameter 185–320μ (mean 263μ), average equatorial diameter slightly greater than axial ; total length including neck 300–520μ (mean 418μ, 50 specimens). Length of neck 120–200μ (mean 155μ, 50 specimens), width at base in average specimen 170μ. Neck consisting of six leaf-like

translucent segments fused together. Six ridges of the same dimensions as the body ridges but not connected to them, rise from the body up the neck, the leaves being folded inwards between them. When the neck opens, splits run from the apex downwards along these ridges, thus separating the leaf-like segments. Average specimen has lower half fused and rigid ; in the opened upper half the separate leaves are often not easily resolved. Spore-body smooth, covered with narrow ridges 10μ broad and 20μ high. These are arranged in a coarse reticulum of 40–50μ diam. or in a nearly regular spiral with an interval of the same size (approximately resembling a *Chara* nucule). Appendages arise at ridge junctions or from slight swellings on the ridges, not less than 50μ apart ; they are thin-walled and translucent throughout their whole length, up to 250μ long, 20μ wide at the attachment, and up to 70μ wide in the club-shaped distal end ; they appear to have been bladders (from the crushed folded walls, Plate XII, fig. 11) and there were 40–50 per spore.

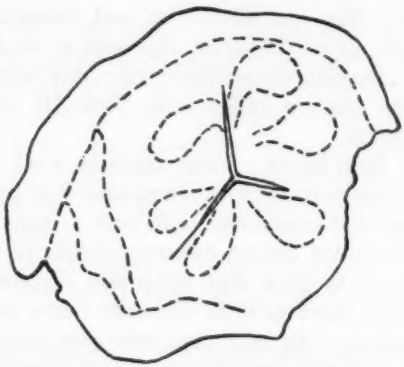
Spore-coat of three layers ; outer exoexine layer 15μ thick, light yellow-brown colour with radially arranged darker bands, giving rise to all appendages and continuous with neck ; inner exoexine layer, 10μ thick, yellow-brown colour, adhering closely to the (innermost) intexine ; this last is 5μ thick, dark red-brown in colour, entire except for small tri-radiate mark at apex (centrally below neck), and has a smooth inner surface. The outer and inner exoexine which are of the same colour are seen in thin sections under high power to be separated, sometimes by a split which probably occurs in sectioning along a surface of weakness. The inner exoexine is seen in section to be interrupted with the intexine at the triradiate laesurae and it disappears from serial sections at the spore apex (just above the base of the neck), Plate XII, fig. 7. In broken specimens under low power, the combined exoexine appears homogeneous and 20–25μ thick. Tri-radiate laesurae are about 50μ long and without adjacent thickening (Plate XII, fig. 10). Within the neck and above the spore proper is a neck-chamber (Plate X, fig. 2) normally about 60μ high, but although its presence is certain the shape of the chamber is not known from many specimens. The six neck ridges appear to arise in three pairs, each pair straddling one of the tri-radiate laesurae as in the diagram, Text-fig. 1. Serial sections (Plate XII, figs. 3–8) illustrate whole structure.

Comparison.—The nearest resemblance is to *P. hexapartita* (Dijkstra) which however lacks the ridges on the spore-body and differs in the appendages ; there is also a difference in proportions of neck and body. *P. medusa* (Dijkstra) (mentioned below) differs in its appendages which are cylindrical, thick-walled (opaque) except at the tip, longer and only 15–30 in number ; the spore-body is smooth and without ridges.

Discussion.—The neck-chamber is comparable with the " andro-

camera" of Nikitin's *Kryshtofovichia africana* at least in section, although externally the Russian spore (of Devonian age) appears to be a *Lagenicula*, but no sections of true Carboniferous *Lagenicula* spores have been examined in this connection.

The tri-radiate scar which suggests the megaspore nature of *P. vectis* is not easily seen. In broken spores it is usually irregularly torn and not identifiable ; in specimens with the neck leaves open the spore is also open and usually filled with sediment. Preparations may be made from suitable spores which have not been too much laterally flattened, by removing most of the neck and by gently dissecting away the lower



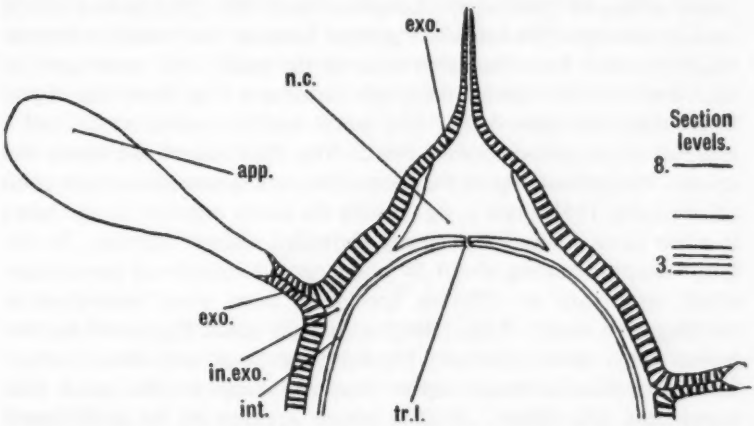
TEXT-FIG. 1.—*Pyrobolospora vectis* gen. et. sp. nov. ; diagram × 200 of view from below of spore-apex (dissection), cf. Plate XII, fig. 10. Broken lines show position of body-wall ridges, and outline of bases of six neck ridges seen through the spore-apex.

two-thirds of the spore. This exposes the apex of the intexine from the inside (Plate XII, fig. 10), and the tri-radiate mark is seen when the specimen is mounted as a transparency. As the spore is small and partly brittle, the dissection is best done on a slightly moist surface.

Terata.—In rather more than two hundred specimens of *P. vectis*, three spores were found (from two localities on opposite sides of the Isle of Wight) each bearing two necks. Two specimens from one of the Sandown localities (S18) are large spores of the type shown in Plate X, fig. 3 ; the sculptine detail is normal with full-length appendages but the two necks have only three leaves each. The other from a Brixton Bay locality (S40B) shown in Plate XI, fig.6, is of normal size but has a second neck at the distal pole ; one neck has three leaves and the other probably four. Zerndt (1934, 1937) figures several abnormalities of the tri-radiate scar in Carboniferous *Triletes* which can be attributed to extra mother-cell divisions, but no explanation is offered in the present case. They are mentioned as they are more frequent than might

be expected (see also *P. hexapartita*) and they may help in the discovery of the origin of these spores.

Terminology.—The outermost layer, *exo.* in text-fig. 2, of the spore-wall with neck and appendages was at first considered as perispore because it stands clear of the tri-radiate scar, but as a working definition of this term is avoided even by Erdtman (1952b, p. 174), his comprehensive term sculptine is used where necessary. However, this outer layer (*exo.*) has radial dark bands and is therefore interpreted as the outer exoexine (see Potonié, 1952) ; the inner exoexine (*in. exo.*) appears identical except for the dark bands. Possibly the terms " exolamellen "



TEXT-FIG. 2.—*P. vectis* sp. nov. ; diagrammatic longitudinal section of proximal half of spore (approx. × 200). *app.*, appendage ; *exo.*, exoexine of neck and ridges ; *in. exo.*, inner exoexine ; *int.*, intexine ; *n.c.*, neck chamber ; *tr. l.*, tri-radiate laesure. Section levels relate to Plate 3, figs. 3–8.

and " isolierschicht " recommended by Potonié could be used. The intexine (*int.*) is quite distinct and is dark brown in colour. This adherence to the priority of Potonié unfortunately excludes the shorter terms used by Erdtman for the same layers ; but Erdtman specifically states that pollen for which his terms are chiefly erected is homologous with *microspores* of heterosporous pteridophytes ; it seems doubtful whether megaspores should still be excluded in view of the subjective implications of function which have become involved in the general use of the name (cf. Doyle, 1953).

Pyrobolospora hexapartita (Dijkstra)

Plate X, figs. 4, 5

1951 *Triletes hexapartitus* Dijkstra. *Meded. geol. Sticht.*, N.S. 5, 14.

Abstract Diagnosis.—Small (150–200μ) dark thick-walled " mega-

spore" covered with short blunt appendages, and with a prominent long (250μ) flame-like neck (Plate X, fig. 4).

Reference Preparations.—S.M. K2247–58.

Locality and Horizon.—Cliffs of Compton Bay, Isle of Wight—north of the Small Chine fault which repeats the Wealden succession (Osborne White, 1951, p. 12); locality S 47. Wealden marls: Bed 11 of this series, described as "Grey clay with large trunks of trees".

Emended description.—Nearly spherical spore-body with equatorial diameter 80–252μ (mean 180μ, 50 specimens); average ratio axial to equatorial diameter 10:11. Total length including neck 280–555μ (mean 430μ, 50 specimens). Length of neck 202–353μ (mean 280μ); neck consisting of six leaf-like segments fused by their margins into six ridges running from the spore-coat up the neck; the centre part of each leaf is folded inward the whole forming a long flame-like organ, larger than the spore-body. The leaves usually display about half a rotation of an anti-clockwise twist. The thickness of the leaves decreases from about 10μ at the base. The neck is sometimes seen open (cf. Dijkstra, 1951, plate ii, fig. 7) with the leaves separate to the base; in a few cases the neck has clearly shrivelled without opening. Spore-body smooth, bearing about 50 blunt opaque cylindrical appendages which may vary in different specimens from mere hemispherical swellings to a length of 30μ; they are usually about 15μ broad and are hollow when seen in section. The full appendage, only seen in about half the spores, is longer (up to 50μ) and bears on the end a thin translucent disc (diam. 20–25μ) which appears to be a collapsed spherical bladder. Spore-coat of three layers:—the exoexine is 15μ thick and yellow-brown in colour forming the neck and appendages; it is divisible into two layers as in *P. vectis*—the outer 12μ with slight radial thickening and the inner only 3μ adhering to the intexine which is 3–5μ thick, red-brown in colour and entire. The apex of the spore proper seems to project upwards and fit closely into the base of the neck; the infolded parts of the neck leaves touch, leaving very little central space in the neck (unlike *P. vectis*).

Discussion.—No tri-radiate scar has been seen but the shape of the spore apex and brittleness of the specimens make this spore difficult to investigate by dissection. The general appearance however of the exoexine and intexine in microtome sections closely resembles the thicker-walled *P. vectis*, and suggests affinity. The size-range of the spore body includes three very small specimens of only about 80μ diameter, the minimum otherwise being 130μ. These small spores are fully developed and have necks about 200μ long but it is noticeable that the necks of all the small spores are open (as are a proportion of those of normal spores); since they were found on the 100-mesh sieve, it suggests that perhaps similar small spores with an unopened neck

were washed through. These would fall in the range of microspore technique and have not yet been seen; the downward limit of size must be left open therefore and with it the meaning of ' megaspore '.

Note.—Dijkstra's two specimens from Kingsclere have been seen but not studied; his description is adequate for the continuance of his name, which is clearly the valid one. Dijkstra describes the spore-body as hemispherical and in fact a few specimens do exceed the ratio given and thus approach this shape.

Comparison.—This spore differs from *P. vectis* in the shorter thicker appendages arising on the spore-coat independently, and not from a network of ridges. The neck is here always much longer than the spore-body diameter, and the neck-chamber is very small or lacking.

Terata.—In about 50–60 specimens so far extracted there has been one large spore with two (reduced) necks of the same type as the *P. vectis* spore shown in Plate X, fig. 3. Another specimen is apparently two normal spores fused together with slight overlap, and with the necks united into a massive structure with twelve leaves (Plate X, fig. 5).

Pyrobolospora pyriformis (Dijkstra)

Plate XI, figs. 1, 2

1951 *Triletes pyriformis* Dijkstra. *Meded. geol. Sticht.*, N.S. 5, 14.

Abstract Diagnosis.—" Megaspore " 500–700μ diam. with broad neck up to 250μ long; spore body covered with short blunt appendages (Plate XI, fig. 1).

Reference Preparations.—S.M. K2259–68.

Locality.—Half-a-mile N.E. of Fairlight Glen foot; cliffs in Middle Fairlight Clay below Coastguard Station; author's locality 80A. (Osborne White, 1928, p. 33).

Emended Description.—Spore-body originally nearly spherical but usually equatorial diameter exceeds the axial. Equatorial diameter 290–920μ (mean 651μ, 35 specimens or mean 631μ including Dijkstra's specimens). The axial measurement with or without the neck is meaningless, as the majority of specimens are asymmetrically laterally flattened (Plate XI, fig. 1); this suggests that the top of the spore below the neck is the most rigid part. Only average maximum neck dimensions are given as the neck is so frequently incomplete; length up to 350μ, width 350–400μ at extremity, narrowing to the base. The neck arises from the spore-body as three prominent folds and consists basically of three bulging lobes between these folds; the specimen in Plate XI, fig. 2, is a small one with somewhat irregular appendages but it shows at the neck attachment a fold centrally, flanked by two downward bulging lobes, with the two other folds at the margins in this view. In most cases the main part of the neck is opaque and ochreous in

colour, and lacking in precise form ; broken surfaces reveal the upper part to be composed of a solid mass of sponge-like tissue without any central canal. Certain complete specimens seem to show a six-fold symmetry of leaves of the neck on the top surface, and others in which the neck is reduced to translucency by maceration show the same number. Spore-body covered evenly with blunt simple or compound appendages 30–40μ high, 40–50μ broad, and seldom less than 15μ apart in an average specimen ; slight decrease in size of appendages towards the neck.

Spore-coat brown to black, consisting of opaque exoexine layer 25–30μ thick and intexine $< 5\mu$ thick and translucent; exoexine layer is likely to be divided as in *P. vectis* but good confirmatory sections have not yet been prepared because of brittleness of specimens. Tri-radiate mark (laesurae 220μ long) seen on inner side of apex of intexine and ? inner part of exoexine in broken specimen. Ideally a neck-chamber is present in the base of the neck but it has not been explored; the swollen lobes mentioned above were seen in some good specimens to be hollow.

Comment.—The tri-radiate scar is believed to be below the neck (as in *P. vectis*) and invisible from outside, but this is not easy to demonstrate clearly. The " tri-radiate ridges " of Dijkstra are probably the wall folds described and his additional plications have been seen in some specimens but they are not regular.

Occurrence.—This spore is never common but has been recorded from several localities in the Fairlight Clays and in the Wealden Marls of the Isle of Wight.

Comparison.—Triletes argus Dijkstra is not considered to be a separate species although the specimen has not been studied ; *P. pyriformis* is very variable in size and in appearance of the neck. Larger appendages more widely scattered are considered to be a result of greater size ; in the very small specimens of *P. pyriformis* the appendages are smaller and more closely packed but probably about the same in total number.

Pyrobolospora medusa (Dijkstra)

1951. *Triletes medusus* Dijkstra. *Meded. geol. Sticht.*, N.S. 5, 14.

Only one further good specimen has been seen from a sample at 777 feet (Wealden) in the Kingsclere No. 1 boring, which extends slightly the range of this rare spore. The neck is not so prominent as the appendages in this species ; although Dijkstra describes tri-radiate ridges, they are not clear in his figure or in my specimen. It seems likely that this species belongs to the group in spite of its possibly trilete neck ; it is quite distinct in spite of the small number of specimens recorded.

Comparable Senonian Spores

Pyrobolospora lobata (Dijkstra)

1949. *Triletes lobatus* Dijkstra. *Meded. geol. Sticht.*, N.S. 3, 25.

Dijkstra describes this as having " three ? or more ? lobes " to the neck with no tri-radiate ridges or contact faces ; he also mentions a " canule " within the neck. Vangerow (1954) confirms but gives very much smaller dimensions for the neck. This Senonian spore has sufficient characters to place it (unexamined) in *Pyrobolospora* rather than *Triletes*.

No attempt has been made to study the remaining *Lagenicula* species of *Triletes*, the first two of which may prove to belong to the new group, and the third to *Aphanozonati*. *T. dictyotus* Dijkstra 1949 is described as having tri-radiate ridges and contact faces ; Vangerow (1954) confirms. *T. capulifer* Dijkstra 1952 is apparently trilete from the figure although the description does not state this clearly. *T. costatus* Dijkstra 1952 is described as having a short neck but the figure is not clear on this point ; *T. lanaris* Vangerow 1954 is almost certainly a synonym but again the figure is not convincing.

Further Consideration of the Organ-genus Pyrobolospora

Dijkstra (1951) thought his species *T. hexapartitus* might be separated from *Triletes* but had insufficient specimens. The three species of *Pyrobolospora* now described are believed to be representatives of a new group distinguishable from *Lagenicula* (sensu Potonié and Kremp), chiefly by their formation of a neck from the outer exoexine and not from a raised part of the whole spore-wall with trilete scar clearly visible. The shape of each of the three neck leaves in *Lagenicula crassiaculeata* (Zerndt) is closely similar to that of each of the six leaves of *P. hexapartita* but the former spore has well developed contact faces.

Contact faces are presumably only present when the separation of the spores of the tetrad is delayed, as in many lycopods. In *Pyrobolospora* the observed sculptine detail can only have been formed on separated spores, and the observed tri-radiate scar (*P. vectis* and *P. pyriformis*) is not so small as to suggest unequal development or abortion of the other spores ; the various terata described support this view. *Pyrobolospora* is not placed in the Division *Triletes*, as this can be done if necessary later, after re-organization (see also next section of paper).

Kryshtofovichia africana Nikitin comes at first sight nearer to *Pyrobolospora* than *Lagenicula* as it lacks contact faces and bears complex (hooked) appendages. In section it appears to have an inner entire spore-wall but also in section each individual neck leaf has

a definite central space suggesting complexity of structure. There are (only) three neck leaves and Nikitin describes the enclosed space as the androcamera, figuring the appropriate microspores within it. Mrs. R. Scott (1906) figures a curious apparently solid neck-like organ on her " Triletes diabolicus " which is perhaps a true *Lagenicula* spore, from the cone *Lepidostrobus foliaceus*. This appears to be similar to the solid " spongy " neck in some specimens of *Pyrobolospora pyriformis*. As suggested by the description of the latter, the varied forms of neck may represent different stages of maturity and function. The genus *Lagenicula* erected apparently on external form is in need of further investigation which should be possible now that its provenance is established.

Chronologically *Pyrobolospora pyriformis* is the earliest species of the new group, being present in the lower part of the Dutch Wealden (Lower Neocomian) and continuing through the English series ; no spore of this type has been recorded from the Jurassic. *P. vectis* and *P. hexapartita* are both from the Upper Wealden Marls of the Isle of Wight and their probable equivalents. Two or three other types have been seen in the English Wealden but so far in too small numbers to describe. Some Dutch Senonian spores are mentioned below but nothing of this type is yet known from later beds. It will be seen from the descriptions that *P. vectis* has been the most fully studied.

C. Triletes Reinsch emend. schopf : Section Aphanozonati Schopf

Two species of megaspore described below are now interpreted as belonging to this group ; the separated perispore of one has been described by Horst (1954) under the name *Dictyothylakos* and presumed to be algal. The old nomenclature is continued for the present, as although Potonié and Kremp (1954) have elevated *Triletes* from a genus to a group in the Carboniferous, no consquent Mesozoic reorganization has yet been attempted.

Triletes galericulatus Dijkstra 1951 emend.

Plate XII, figs. 1, 2

Abstract diagnosis.—Smooth black megaspore about 350μ diameter ; tri-radiate ridges and pointed appendages together often form an apparent low neck.

Reference Preparations.—S.M. K2269-71.

Locality and Horizon.—Cliff 200 yards N.E. of Cliff End Point, near Fairlight, Sussex ; Lower Ashdown Sand, locality 48 B. (Osborne White, 1928, p. 33).

Emended Description.—Spore-body has rounded equatorial outline and an average diameter 300–400μ (mean 345μ, 30 specimens). Tri-radiate ridges prominent 200μ long, 50μ high, and 20μ broad ; the

upper part of the contact face in each inter-radius bears three or more upwardly directed spines 100μ long, 20μ diam. at their bases and tapering to a point (Plate XII, figs. 1, 2) ; the arrows on the two figures indicate the same point on the periphery. Spore coat black or dark brown, smooth, 20μ thick. In certain lateral compressions (Dijkstra, Plate ii, fig. 16) there may be an elliptical outline but the spore is believed to have been essentially spherical.

Comment.—In nearly all specimens the space between the spines and tri-radiate ridges is packed with sediment and the structure is only revealed after cleaning with hydrofluoric acid. Although Dijkstra's description leads to the classification of the spore in the section *Lagenicula*, his second figure (Plate iii, fig. 5) appears to show one of the spines separated. Arcuate ridges mentioned by Dijkstra have not been seen but the present illustration suggests that the thickness of the wall may give the appearance of such a structure.

Comparison and Discussion.—No other spore of this type has been found in the Wealden. The change in classification of this pore removes the last member of the section *Lagenicula* in the Wealden (Dijkstra, 1951).

Occurrence.—*T. galericulatus* also occurs rarely in the Upper Fairlight Clay and never more than three specimens have yet been recorded from any one sample.

Triletes retiarius sp. nov.

Plate XI, figs. 3, 4

1954 *Dictyothylakos pesslerae* U. Horst (pars) Geologie, Berlin, 3, 610–613.

Type Preparations.—S.M. K2271–5.

Locality and Horizon.—Author's locality S47 (see under *Pyrobolospora hexapartita*) ; Wealden Marls, Isle of Wight.

Description.—Trilete megaspore, probably spherical but the whole upper (apical) surface may be preserved infolded (Plate XI, fig. 3). Diameter 520–700μ (mean 620μ, 6 specimens). Tri-radiate ridges 200μ long, 10μ broad, and 30μ high ; contact faces smooth except in one specimen where the perispore covers the whole spore surface. Distal hemisphere entirely covered (Plate XI, fig. 4) with a mesh-like (net) perispore sometimes in different layers of different mesh size. The chief mesh strands are 15–35μ wide and 10μ thick (Plate XII, fig. 9) but may also be circular in cross-section exactly as described and figured by Horst (1954) and figured by Michael (1936). Spore coat is brown but shows a red luminous effect in places : thickness of exoexine 15μ, intexine very thin 2–3μ and continuous with tri-radiate lips.

Occurrence.—Pieces of detached mesh have already been seen in

samples from seven quite separate Wealden localities in England, in addition to the German localities.

Comment.—This does not necessarily account for some of the larger pieces of mesh (up to 4·5 mm. long) described by Horst, although they could perhaps be unrolled perispore from larger specimens. Two further specimens found here consist of large pieces (5–6 mm. long) of the cutinized coat of an unknown body of about 1 cm. diam. and perhaps spherical. The coat is 50μ thick with apparently also a very thin inner layer ; there are patches of irregular mesh perispore of the type described above, attached to the outside surface. No suggestion can yet be put forward about the identity of these parts of larger objects, but Horst's attribution to the *Algae* is considered unlikely ; Seward (1913, p. 103) describes and figures scales of *Eury-Cycadolepis* which bear a raised reticulum although it is on a larger scale than *Dictyothylakos* in the specimens concerned. A microspore, *Dictyotriletes* Naumova with this type of perispore was described in 1937.

In addition to other bodies it seems possible that with further specimens there may prove to be more than one ordinary megaspore like *T. retiarius* with variants of this type of perispore.

Derivation of Name.—Lat. *retiarius*, the net-fighter.

V. Notes on the Descriptions

The recommendations of the Palynology Conference at the Third Heerlen Carboniferous Stratigraphy Congress (Dijkstra in Erdtman, 1952) are followed, except that greater magnification ($\times$ 100) is used for most figures ; this is considered justifiable if it is clearly stated and if a simple multiple of 50 is used. The magnification ($\times$ 50) was obviously chosen for the much larger Carboniferous spores. The various measurements given for spores are known to be imperfectly expressed by a simple mean value ; the use of space necessary, however, for a fuller record is not considered justified as size alone is of little value with megaspores. Colour of spore-coats is given as it may be helpful but the state of preservation and the degree of treatment can obviously alter it.

Adequate photography has not yet been possible owing to depth of focus required on such small objects, and the different lighting frequently required for appendages and spore-body. Author's locality numbers given will be amplified where necessary in a subsequent paper.

VI. Botanical Attribution of Dispersed Megaspores

There is little to add to Dijkstra's discussion (1951) of the possible heterosporous plants which could have borne these spores. The various members of the *Lycopodiales* are probably represented by the *Aphanozonati* and *Zonales* sections of *Triletes* in the sense of Dijkstra ; his

reference (1951, p. 17) to " possible *Hydropterideae* " (presumably *Marsiliaceae*) in the German Wealden is clarified by the kindness of Dr. Hiltermann who sent me photographs of the spores ; they are almost certainly *Triletes pseudotenellus* Dijkstra of the section *Zonales*, and thus probably from lycopods.

The *Pyrobolospora* group of spores appear to be quite separate, although it is as well to record that they occur in the same samples as *Aphonozanati* and *Zonales*. The elaborate and delicate appendages of *P. vectis* and *P. medusa* suggest aquatic habit ; on the other hand authors including Vakhrameiev (1947) stress that one of the major factors in the northern hemisphere Lower Cretaceous world was rapidly increasing aridity, and this group is so far confined to the Cretaceous. The function of the various types of neck cannot be guessed until more material has been studied.

Although records of derived spores are becoming more numerous (Teichmüller, 1953), that complication is considered very unlikely at least in the case of *Pyrobolospora vectis* and *P. hexapartita*, as relatively few specimens are even damaged.

The possibility of discovery of new heterosporous groups is emphasized in an article on the *Noeggerathiinae* by Halle (1954), although that group is not involved here. Even the use of the term " megaspore " where microspores are not seen should really be open to criticism ; the arbitrary nature of the size limit of 200μ will be seen from the size-ranges given in this paper.

VII. General Remarks

Papers quoted and unpublished work separate the Middle Jurassic, Wealden, and Senonian megaspore floras in one province (Britain and the Netherlands) which are quite distinct from each other ; in my opinion there is reasonable prospect of continuing the process to finer sub-divisions. Gilbert and Harris (1953) and Jongmans (1952, p. 12) both also take an optimistic view of this problem, the plant microfossils not being confined to megaspores. From the point of view of evolution of floras it is perhaps worth noting a rather greater similarity (in this small megaspore section) between Wealden and Senonian than between Middle Jurassic and Wealden.

Acknowledgments

Dr. H. Hamshaw Thomas, Professor T. M. Harris, Professor P. Allen, and Dr. S. J. Dijkstra have frequently helped me with generous advice. The drawings have been made with great patience by my wife, Pamela Hughes. Mr. W. Stigwood has very kindly assisted me in making sections of some of the spores.

All the specimens are from the author's collection and the preparations numbered S.M. are deposited in the Sedgwick Museum, Cambridge.

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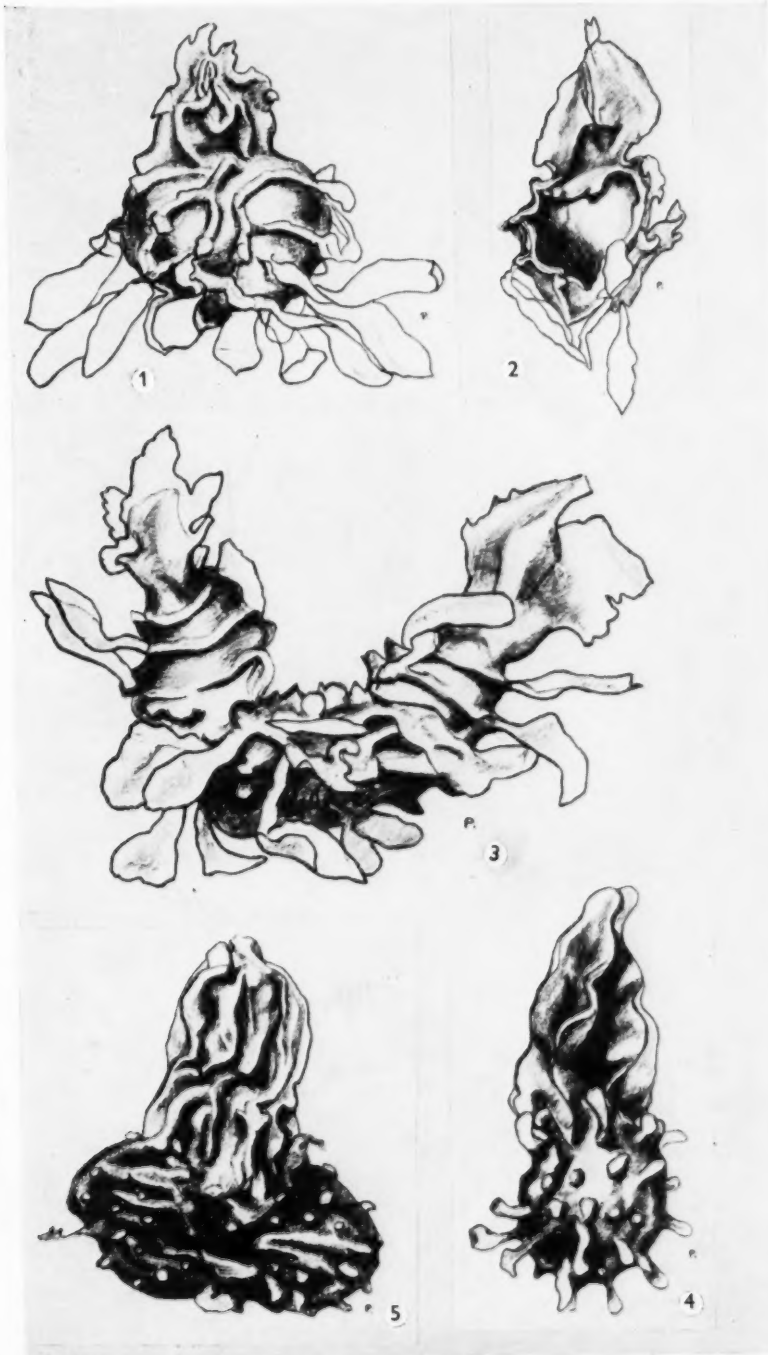

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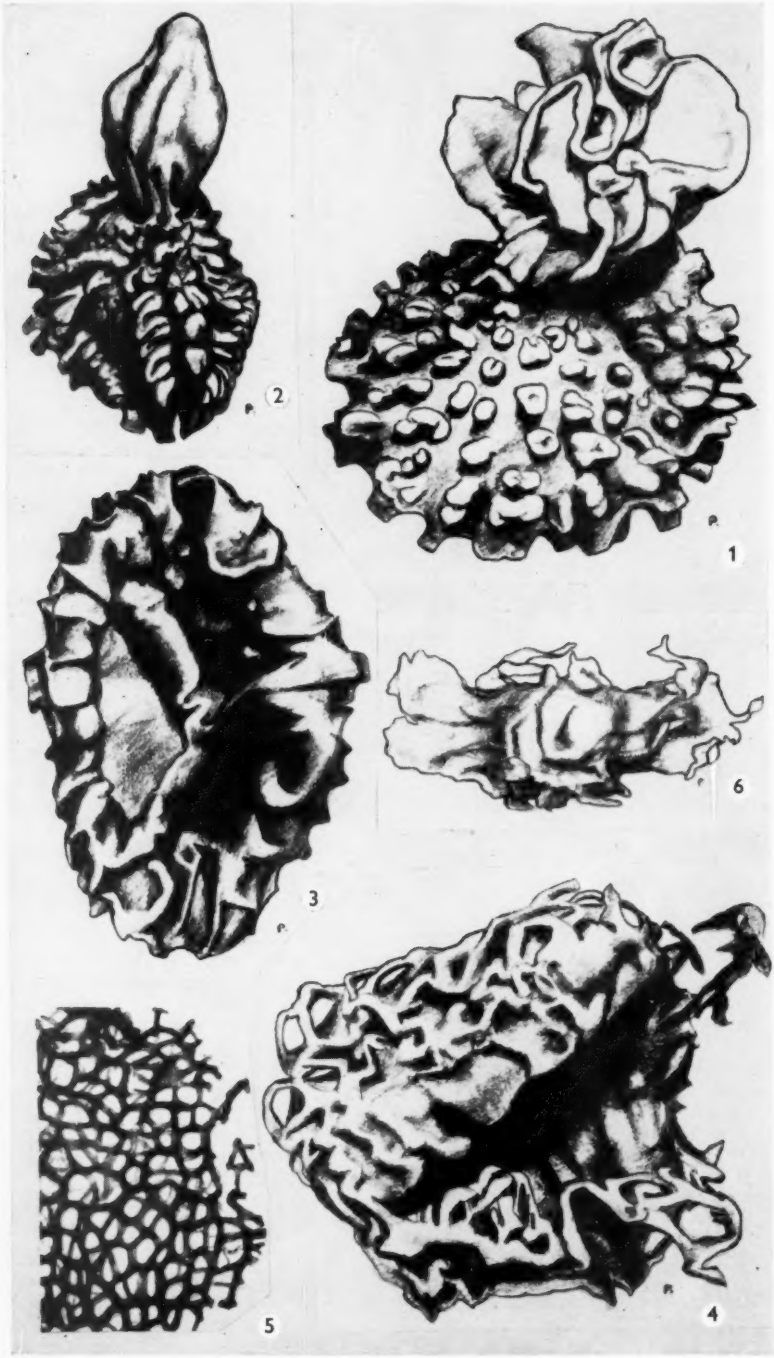

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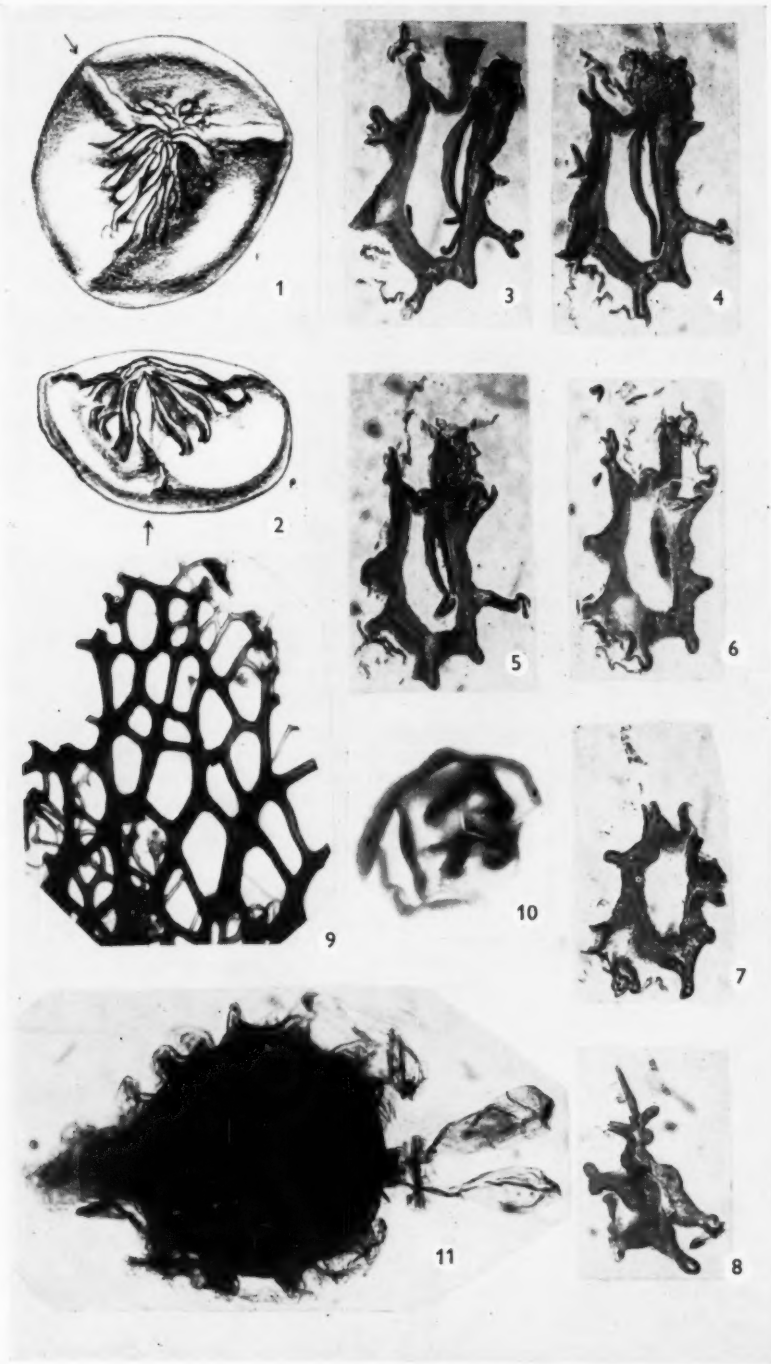

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EXPLANATION OF PLATE X

FIGS. 1–3.—*Pyrobolospora vectis* gen. et sp. nov. Wealden Marls (S18), Sandown, Isle of Wight. × 100.

1. Spore with some appendages removed.
2. Broken spore showing neck chamber.
3. Large spore with two necks.

FIGS. 4–5.—*Pyrobolospora hexapartita* (Dijkstra). Wealden Marls (S47), Compton Bay, Isle of Wight. × 100.

4. Typical spore.
5. Specimen consisting of two spores with necks united.

EXPLANATION OF PLATE XI

FIGS. 1–2.—*Pyrobolospora pyriformis* (Dijkstra). Fairlight Clay (80A), Covehurst Bay, near Hastings. × 100.

1. Spore showing body-fold (left centre) running up into neck, and neck lobe (right centre) projecting down.
2. Small specimen with complete neck, showing three body-folds and two lobes.

FIGS. 3–4.—*Triletes retiarius* sp. nov. Wealden Marls (S47), Compton Bay, Isle of Wight. × 100.

3. Spore with proximal hemisphere infolded.
4. Spore with perispore partly detached.

FIG. 5.—*Dictyothylakos* sp. Wadhurst Clay (113A), Cooden, Sussex. × 100. Detached perispore fragment. (Phot.)

FIG. 6.—*Pyrobolospora vectis* sp. nov. Wealden Marls (S40B), Brixton Bay, Isle of Wight. × 100. Specimen with two necks.

EXPLANATION OF PLATE XII

FIGS. 1–2.—*Triletes galericulatus* Dijkstra. Ashdown Sands (48B), Cliff End, near Hastings. × 100. Two views of same spore.

FIGS. 3–8.—*Pyrobolospora vectis* sp. nov. Wealden Marls (S18), Sandown, Isle of Wight. × 100. Serial sections (see Text-fig. 2). (Phot.)
3, zero ; 4, + 7μ ; 5, + 14μ ; 6, + 21μ, apex of spore ; 7, + 35μ, neck chamber ; 8, + 63μ, neck.

FIG. 9.—*Triletes retiarius* sp. nov. Wealden Marls (S47), Isle of Wight. × 100. Detached perispore from type locality.

FIGS. 10–11.—*Pyrobolospora vectis* sp. nov. Same locality as above (S 18). × 100. (Phot.)

10. Dissection of spore-apex showing tri-radiate laesurae from below. See also Text-fig. 1.
11. Spore showing two translucent appendages.

The Upper Carboniferous Rocks of the Stainmore Coalfield

By T. D. Ford

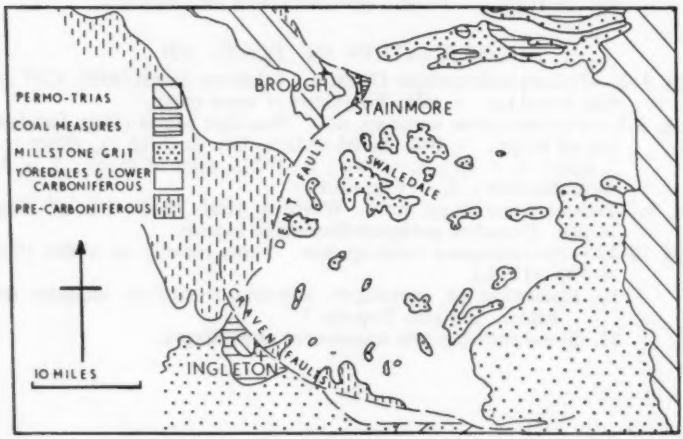
Abstract

The sequence of Upper Carboniferous rocks in the outlier at the western end of Stainmore Pass is described. The Upper Yoredale Series is shown to be separated by an unconformity from the overlying "Millstone Grit" series. The Coal Measures are about 800 feet thick and appear to be unconformable on the "Millstone Grit". Hitherto unrecorded non-marine faunas and floras indicate horizons near the base and at the top of the Modiolaris zone. The sequence of Upper Carboniferous rocks at Stainmore is briefly compared with those of surrounding coalfields.

I. Introduction

At the western end of the Stainmore Gap (Old Series 1 in. sheet 102 S.E.) an outlier of Coal Measures covers an area two miles from north to south and up to half a mile wide. Exposures are largely confined to the banks of deeply incised streams flowing towards the Vale of Eden.

The outlier is bounded to the north-east by the Pennine Fault system and on the south-east by the Dent Fault System. Both throw Yoredale beds against various horizons of the Coal Measures. On the western margin the "Millstone Grit" and Yoredale Series crop out from beneath the Coal Measures; all have easterly dips increasing in amount towards the Pennine and Dent Faults. Productive Coal Measures outcrop only in Argill Beck, where mining has been carried



Text-fig. 1.—Sketch-map to show the position of the Stainmore Coalfield.

out on a limited scale by adits driven into the banks south of Gillbank House. No mining is carried on at present.

The existence of Coal Measures in Westmorland was apparently first made known by J. G. Goodchild in 1870. No memoir was published for this sheet (102 S.E.), but Goodchild wrote a report for the landowners in 1872, which has not been located. Later (1890) he briefly mentioned the occurrence at Stainmore of twenty coal seams one of which reached a thickness of eight feet. Through the kindness of the Director and Mr. W. Anderson (of the Newcastle Office) of the Geological Survey, the author has examined Goodchild's field slips and tabular sections of the strata. There are discrepancies between these, and considerable difficulty has been experienced in relating Goodchild's data to the section constructed from present-day exposures. From the brief notes added to Goodchild's sections and field slips it would appear that other more recent investigators, including J. R. Dakyns, T. Eastwood, and B. Smith, have found similar difficulties.

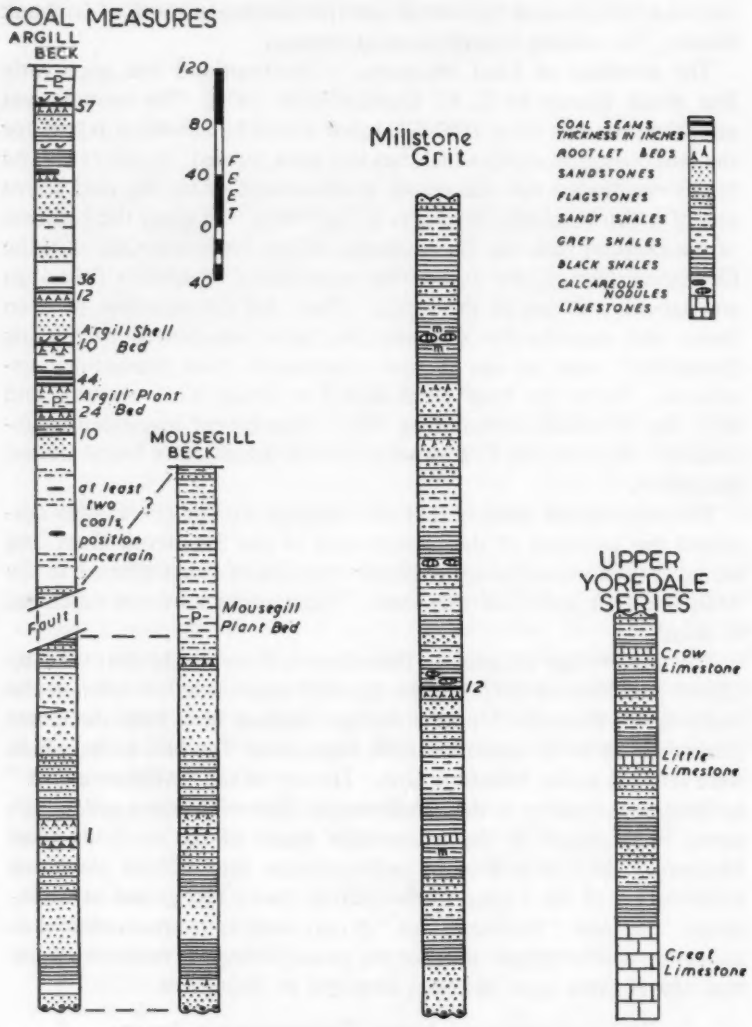
The most recent work is that of J. Selwyn Turner (1935) who described the tectonics of the western end of the Stainmore Gap, and included on his map the approximate outcrops of strata referred to the Millstone Grit and Coal Measures. These rocks were not described in detail.

The terminology adopted in this account is similar to that used by Chubb and Hudson (1925) in the Tan Hill area some five miles to the south-east. There the Upper Yoredales include beds from the Great Limestone up to the unconformable base of the Tan Hill Grits, which were referred to the Millstone Grit. The top of the " Millstone Grit " at Stainmore is taken at the conglomeratic base of a higher grit, which seems to be linked to the sedimentary cycles of the overlying Coal Measures. Discontinuities in sedimentation thus delimit the three subdivisions of the Upper Carboniferous rocks recognized at Stainmore. The term " Millstone Grit " is here used in inverted commas as indicating a lithological unit, for no palaeontological evidence of the true age of these beds has been obtained at Stainmore.

II. Succession of Upper Carboniferous Strata

(*a*) *General*

The most important section in the area is that in Argill Beck, where an ascending sequence of beds is exposed upstream from Argill Bridge (Text-fig. 3). As there are several faults crossing the stream and also several large gaps in exposure, reference must be made to the tributary stream, Mousegill Beck, to establish a more complete succession (Text-fig. 2). The River Belah and its tributaries about half-a-mile to the south, and Augill Beck, about a mile north-west, exhibit less



TEXT-FIG. 2.—Successions of the Upper Carboniferous Rocks in the Stainmore Coalfield.

complete successions. The Upper Yoredale Series is exposed in these streams from Argill and Oxenthwaite Bridges eastwards for about a third of a mile. The " Millstone Grit " follows to the east with a discordant base, although no major unconformity has been detected within the area. The Coal Measures contain strong sandstone bands in the lower portion of the sequence, apparently resting discordantly

upon the " Millstone Grit ". Only in the higher part of the Coal Measures do workable coals appear and these outcrop only in Argill Beck up to within a few yards of the Dent Fault near Gillbank Farm (Nat. Grid. Ref. 35/841137). In all these beds dips increase steadily upstream, the Upper Yoredales at about 15–30°, the " Millstone Grit " 30–45°, and the Coal Measures up to vertical.

No diagnostic fossils have been obtained from the Upper Yoredale Series or " Millstone Grit ", but the Coal Measures have yielded non-marine lamellibranch faunas and floras from two horizons. Red-staining of the measures is frequent and is probably related to the former overstep of Permo-Triassic rocks, which outcrop about two miles to the west.

(*b*) *Details*

(i) *Upper Yoredale Series.*—The series consists of some 300 feet of sandstones, shales and limestones exposed in Argill and Mousegill Becks, in the River Belah and its tributaries (Text-fig. 3) and in Augill Beck (not shown on map—about one mile north-west of Argill Beck). The base of the series is taken at the Great Limestone upon which Argill and Oxenthwaite Bridges are built. It consists of some 60 feet of coarse crinoidal limestone, thinly bedded towards the top and partly haematitized in places. Above it a marine shale development passes up through sandy shales and flags into fine-grained massive sandstones which form a prominent bluff about a quarter of a mile north-east of Argill Bridge (35/827131). These are capped by the Little Limestone, some 10 feet of thinly bedded, sometimes nodular, argillaceous limestone, sometimes partly silicified, with crinoid ossicles. This is faulted out of Argill Beck, but is repeated by faults in Mousegill Beck west of Stricegill Farm, and in the River Belah. The cyclothem of dark shales passing up through flags into fine-grained sandstone, with minor oscillations, is repeated and capped by the foot-thick Crow or Crag Limestone, about 80 feet above the Little Limestone. The Crow Limestone occurs as bands of close-set nodules where Coldkeld Beck (35/829110) and Hocker Gill (35/830117) join the River Belah, and as a thin dark limestone in Argill Beck near Longclose Gill (35/831133). Thick black shales passing up into flags in places follow and are discordantly overlain by the conglomeratic base of the " Millstone Grit ".

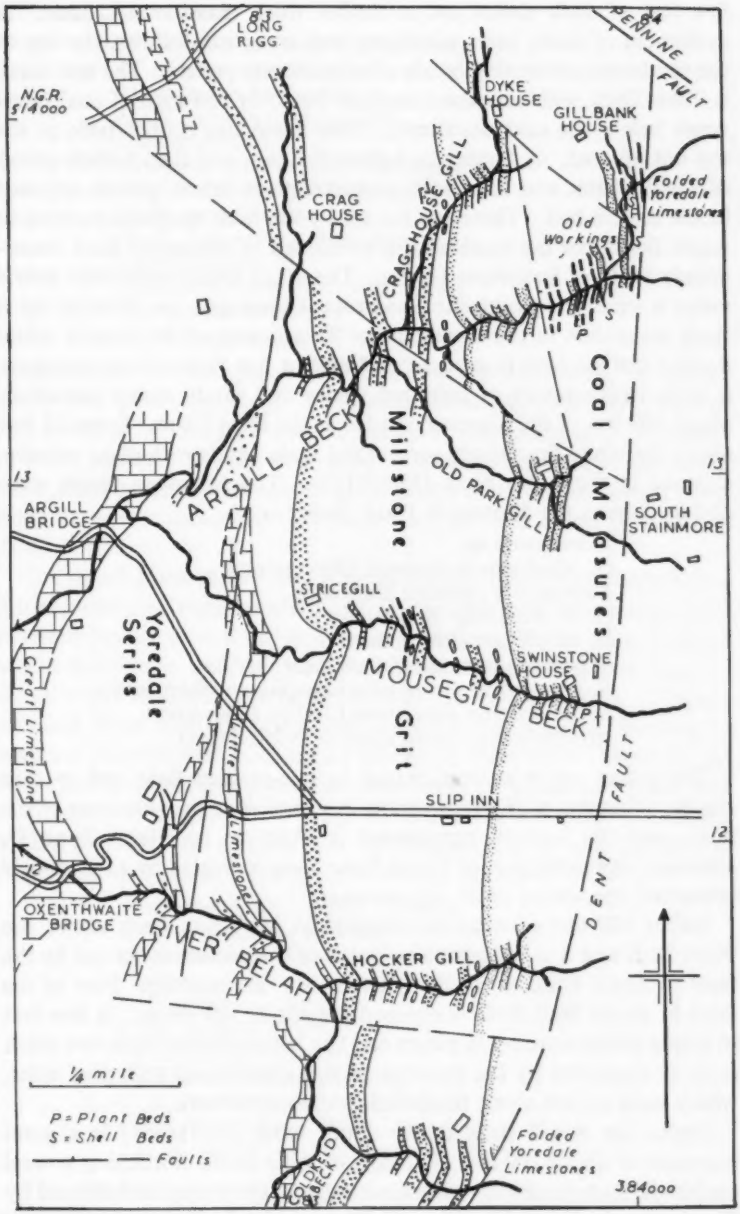
(ii) " *Millstone Grit* ".—In the Stainmore Coalfield area the " Millstone Grit " consists of some 630 feet of sediments occurring in cyclothems similar to the underlying Yoredale Series, except that the limestones are rarely more than a few inches thick and are generally represented by nodules or calcareous shale. The " Millstone Grit " is well exposed in Mousegill Beck for about a third of a mile east of

Stricegill Farm, with easterly dips of 30–50°. The base is marked by a massive coarse felspathic grit, pebbly at the base. This makes the strong feature on which Stricegill Farm stands (35/830126) and provides waterfalls some 20 feet high in Hocker Gill (35/831117) and Intake Gill (35/830110). A conglomeratic base is well seen in Augill Beck (35/820153) and in Coldkeld Beck (35/826106). The basal grit is followed by at least six cyclothems of limestone, shale, sandy shale or flags, grit, shale, limestone. Some of the grits have rootlet markings at the top, but only in one case, in Mousegill Beck, is there a fireclay and coal, the latter about a foot thick. The individual grits are up to 20 feet thick, medium grained and massive, generally with red colouring in patches. The lowest of the limestones is about a foot thick and outcrops in Argill Beck, due south of Crag House (35/833133), in Mousegill (35/833126) and in the River Belah (35/832112). Calcareous nodule beds only occur in most of the higher cyclothems and are not well exposed. The highest limestone occurs as large bullions close together in Mousegill (35/836125), but in Argill Beck close to the mouth of Crag House Gill there are two separate beds of limestone each about 9 inches thick. Turner (1935) interpreted these as a faulted inlier of Fell Top Limestones, but less than a quarter of a mile downstream a considerable thickness of the Upper Yoredale Series, including both the Fell Top Limestones and the underlying Mirk Fell Beds of the Tan Hill area, are apparently overstepped by the unconformable basal " Millstone Grit ". Productid remains and crinoid ossicles occur in marine shales immediately above the limestones in both sections.

(iii) *Coal Measures.*—Beds here referred to the Coal Measures total 800 feet in thickness and are exposed in Argill and Mousegill Becks (Text-fig. 2). Neither of these exhibits an unbroken section and only the former contains the workable coals. A fault separates these from the lower arenaceous beds in Argill Beck and also cuts out the highest beds seen in Mousegill Beck from the Argill Beck section.

The Coal Measures can be separated into two groups, a lower dominantly sandy division without coals, about 300 feet thick, and an upper dominantly shaly division with at least ten coals visible *in situ*. Others are believed to occur but their approximate position is known only from old adits and tips. Subsidiary outcrops of the sandy division occur in Crag House Gill, Old Park Gill, and Hocker Gill.,

The beds here adopted as marking the base of the Coal Measures consist of a coarse felspathic sandstone 15 feet thick, with shale-conglomerate bands towards the bottom. In Argill Beck a few inches of rubbly ganister are seen below it, whilst in Mousegill Beck (35/836125) the conglomeratic base trangresses 4 feet of the underlying sandy shales of the " Millstone Grit ". Lack of palaeontological evidence precludes the identification of these basal beds as being of



TEXT-FIG. 3.—Sketch-map of the Stainmore Coalfield.

Coal Measure Age. Above the basal sandstone in Argill Beck are a few feet of dark shales and a further thick massive sandstone. A cyclothem of shale, flags, sandstone and seat-earth follows, the top of the sandstone containing bands of rolled sandy pellets. The seat-earth is 9 feet thick with abundant rootlets, but only one inch of coal intervenes below the next sandstone. This again has rootlet beds at the top but no coal. A further cyclothem follows, and then a thick group of sandy shales and flags with scattered plant debris, poorly exposed in the stream bed. These are cut off by the fault mentioned above in Argill Beck, but the succession is continued in Mousegill Beck immediately south of Swinstone House. The sandy shales with plant debris make a small crag opposite Swinstone House and are overlain by a thick sandstone in the stream bed. This is capped by a thick white fireclay but no coal is exposed and after a few feet without exposure a thick development of light red shales and sandy shales constitute about 100 feet of the succession as far as the Dent Fault. Some 25 feet above the white fireclay are several red shale bands with plant remains exposed in the south bank (35/837124). The following plants were obtained from the Mousegill Plant Beds :—

Mariopteris sp.
cf. *Alethopteris davreuxi* (Brongniart)
Neuropteris gigantea Sternberg
cf. *N. tenuifolia* (Schlotheim)
cf. *N. obliqua* (Brongniart)
Sphenophyllum cuneifolium (Sternberg)
S. cuneifolium forma saxifragaefolium (Sternberg)
Bothrodendron punctatam Lindley & Hutton
Asterophyllites equisetiformis (Schlotheim)

The plants occur as impressions in fine-grained light red or lilac shales. Pinnules of *N. gigantea* and *S. cuneifolium* provide most of the flora, and the horizon represented is likely to be Floral Zone D, although representatives of Floral Zone E are indicated by a few poorly preserved specimens of cf. *A. davreuxi.*

About 100 feet of beds are exposed in Mousegill Beck above the Plant Beds and it is not clear how much of this section is cut out by the fault in Argill Beck or whether further beds are missing. East of the fault in Argill Beck little is exposed for about 100 yards. A few feet of sandy shales outcrop in places and the presence of at least two thick coals is suggested by the presence of tips outside old collapsed adits, which were driven along the strike in the north bank.

Higher up Argill Beck in the south bank (35/838135) is a good exposure of about 100 feet of steeply dipping strata containing several coals. A thin sandstone with an overlying 10 in. coal is followed by flags and a further 2 feet of coal. The roof of the latter coal consists of about 15 feet of coarse light grey shales with abundant plant remains

at several horizons. These, the Argill Plant Beds, have yielded the following plants :—

Mariopteris muricata (Schlotheim)
M. cf. *coarctata* Stur
M. cf. *acuta* Brongniart
M. cf. *nervosa* (Brongniart)
Diplotmema sp.
Neuropteris heterophylla Brongniart
N. cf. *tenuifolia* (Schlotheim)
N. cf. *gigantea* Sternberg
N. cf. *heterophylla* Brongniart
Lepidophyllum sp.
Cyclopteris orbicularis Brongniart
Myriophyllites gracilis
Cordaites principalis (Germar)

The most abundant plants in this flora are small fronds, *N. heterophylla* and *Mariopteris* spp. Variants of *N. heterophylla* show tendencies towards *N. tenuifolia* and *N. grangeri*. *Diplotmema* sp. is present in some numbers but not abundant. Although the flora of the Argill Plant Beds is rather different in proportions from the Mousegill Plant Beds, it is still indicative of Floral Zone D with some elements of Zone E present.

The Argill Plant Beds pass up imperceptibly into rootlet beds below a composite coal seam consisting of 44 inches of coal interbanded with pyritous ironstone and crushed shale. The roof shales contain occasional fish scales and fragments of plant stems referred to *Lyginodendron* sp. About 20 feet higher a 10 in. coal is overlain by 18 inches of black shale with abundant non-marine lamellibranchs, forming in places a mussel-band, here called the Argill Shell Bed. Many of the shells are crushed, but a considerable fauna of uncrushed shells was obtained. A representative fauna of this band was kindly examined by Dr. J. Weir, who concurs that the horizon is at or near the base of the Modiolaris zone. The fauna collected includes :—

Anthraconaia cf. *curtata* (Brown)
A. cf. *williamsoni* (Brown)
cf *Anthracosphaerium boltoni* (Wright)
Carbonicola aff. *os-lancis* Wright
C. cf. *os-lancis* Wright
C. cf. *antiqua* (Brown)
C. cf. *bipennis* (Brown)
C. cf. *polmontensis* (Brown).
C. cf. *martini* Trueman & Weir
C. cf. *rhomboidalis* Hind
? *C.* cf. *rectilinearis* Trueman & Weir

The dominant form has been referred to *C.* aff. *os-lancis* Wright. In proportions there is close similarity with the forms described by Wright and by Trueman & Weir, but the Argill shells are generally

smaller. Some are elongated and resemble *C. antiqua* (Brown) whilst small shells referred to *C.* cf. *bipennis* are not uncommon. A number of poorly preserved small shells appear to be close to *Anthracosphaerium boltoni* (Wright), whilst a few large *Anthraconaia* spp. are scattered through the community. Thus elements of both Communis and Modiolaris zones are present and an horizon close to the base of the Modiolaris zone is indicated. The poor specimen doubtfully referred to ? *C.* cf. *rectilinearis* cannot be regarded as diagnostic of any lower horizon.

The Argill Shell Bed is capped by a thin sandstone close to the mouth of a small tributary, where adits have been driven for two coals, one of which is completely visible and 12 inches thick, the other only partly seen in the bed of the tributary is at least 3 feet thick. For about 100 yards up Argill Beck exposure is poor until a landslip scar on the south bank shows some 20 feet above a sandstone. A few poorly preserved and unidentifiable lamellibranchs were found in ironstones weathered out of these shales.

These last beds outcrop again beyond a small fault, but the exposure of the remaining 100 feet or so of beds up to the Dent Fault is poor. Among them is a coal 4 feet 9 inches thick once worked from an adit in the north bank west of Gillbank footbridge (35/840138). The coal dipped at 65° E. in the workings but is no longer seen at outcrop. The tip, now being eroded by the stream, yields blocks of poor quality powdery coal and occasional internal casts of *Anthracosia* spp. in ironstones. These are poorly preserved but two specimens have been tentatively identified by Mr. M. A. Calver as *Anthracosia* cf. *nitida* (Davies & Trueman) and *A.* cf. *disjuncta* Trueman & Weir. There are some suggestions of a further thin coal and fireclay a few feet below this. The thick coal is overlain by some 25 feet of reddish grey shale which is crushed and faulted under the footbridge. This shale has yielded plant remains which include :—

Alethopteris lonchitica (Schlotheim)
A. cf. *lonchitica* (? cf. *A. decurrens* (Artis))
Neuropteris heterophylla Brongniart
N. gigantea Sternberg
N. obliqua forma impars Weiss
N. cf. *obliqua* (Brongniart)
Calamites suckowi Brongniart
Asterophyllites charaeformis (Sternberg)

The most abundant elements in the flora are small fronds of *N. heterophylla* and *Alethopteris lonchitica.* Variants of the former approach *N. callosa* and *N. grangeri.* Some of the *Alethopteris* fronds show characteristics intermediate between *A. lonchitica* and *A. decurrens.* Such an assemblage of plants might occur in Floral Zones D or E, but when considered in their close proximity to *Anthracosia*

spp. as mentioned above, the horizon of these beds is most probably high in the Modiolaris zone. Some twenty years ago a small collection of very poorly preserved shells in reddish grey shales were obtained by J. Selwyn Turner from a locality 800 yards east of Crag House Farm, i.e. close to the above-mentioned plant and shell bands near Gillbank footbridge. This band has not been rediscovered and the specimens now in the Geological Survey Collection (Nos. 52943–50), although showing some resemblance to the *Anthraconaia pruvosti* group, probably represent the *A. pulchra* (Wright non Hind) fauna which occurs near the base of the Similis-pulchra zone in Lancashire.

Between Gillbank footbridge and the Dent Fault some 15 yards upstream the thick coal and its associated shales appear to be repeated with almost vertical dips to the west, and an adit a few yards north of the footbridge has a tip yielding blocks of brecciated powdery coal. Beyond the Dent Fault Yoredale limestones and shales are seen isoclinally folded and much faulted.

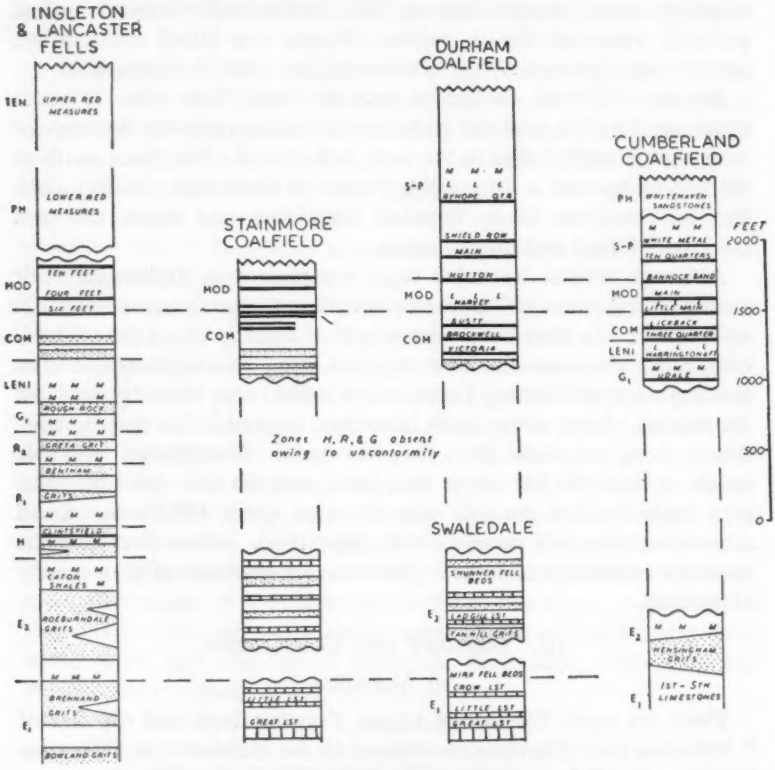
Although several workable coals are present at Stainmore, their average dip is about 60° towards a boundary fault only some 300 yards to the east. As their maximum length of outcrop along the strike is only about three-quarters of a mile, assuming no complications from faulting north of Gillbank Farm, only a limited area of coal is available for mining. Most of the coals have been worked in the past by adits driven along the strike from the river bank. The greatest workable height is about 60 feet above river level, and the only available mine plan indicates that the adit only extended about 100 yards. Small reserves are thus still present above water level. Below river level the coals are believed to be intact. The coals are generally of poor quality at outcrop.

III. Summary and Conclusions

(*a*) *Namurian*

There are some 300 feet of Upper Yoredale beds and 630 feet of " Millstone Grit " tentatively referred to the Namurian at Stainmore (Text-fig. 4). This succession is similar to that in Swaledale, but about 200 feet thinner and contains one major difference. As noted earlier the thick Mirk Fell Beds of Swaledale appear to be cut out by unconformity at the base of the " Millstone Grit " at Stainmore. Since the Mirk Fell Beds were shown by Hudson (1941) to occur at the base of the Upper Eumorphoceras Stage, the Upper Yoredales of Stainmore are probably all of E_1 age. Comparison of the " Millstone Grit " succession at Stainmore with that published by Chubb and Hudson (1925) for Swaledale indicated that the basal grit is probably the Tan Hill Grit, whilst the highest limestones may be equivalent to the Shunner Fell Beds, which Trotter (1952) correlated with the Colsterdale

Limestone of upper E_2 age. The unconformable base of the Millstone Grit was shown (Chubb & Hudson 1925) to step downwards to the south-east towards Grassington, where strata of E_1 age rest unconformably on Lower Carboniferous rocks. To the north Carruthers (1938) has shown that the plane of unconformity rises with but minor irregularities, and it is believed that the Stainmore sequence shows westward overstep on to lower beds.



TEXT-FIG. 4.—Suggested correlation of the Upper Carboniferous rocks of the Stainmore Coalfield with those of Ingleton and the Lancaster Fells (Ford, 1954), Swaledale (Hudson, 1941, and Trotter, 1952), Durham (Eastwood, 1953), and West Cumberland (Trotter, 1954).

The Namurian succession at Stainmore is in marked contrast to the recently established succession at Ingleton (Ford 1954) where about 1,000 feet of beds occur within the *Homoceras*, *Reticuloceras*, and *Gastrioceras* zones, and show a typical Millstone Grit development. It is clear that between Ingleton and Stainmore there were considerable changes in environment and consequent sedimentation during much of Namurian times.

Comparison of the Stainmore succession with the imperfectly known succession in the Cumberland Coalfield indicates that although sedimentation occurred in both areas at the same time, the detailed sequences are somewhat different, the Hensingham Grits of Cumberland apparently being of similar age to the " Millstone Grit " of Stainmore. The *Homoceras* and *Reticuloceras* zones are unrepresented in both areas, but sedimentation appears to have recommenced earlier in Cumberland with the occurrence of beds of Lower Gastrioceras Age for the presence of which there is no evidence at Stainmore.

(*b*) *Ammanian*

The Coal Measures at Stainmore consist of about 800 feet of beds including at least 12 coal seams, and these measures appear to be entirely of Ammanian Age. However the principal fossil horizons all occur towards the upper part of the sequence and the exact age of the lowest beds remains doubtful. The lamellibranchs of the Argill Shell Bed indicate an horizon at or near the base of the Modiolaris zone, whilst the flora, though less conclusive, indicates a comparable position near the top of Floral Zone D. Restricted faunas and a flora from some of the highest beds in the sequence suggest an age near the top of the Modiolaris zone. The arenaceous beds below the fossil horizons probably belong to the Communis zone or they may also include some part of the Lenisulcata zone. The basal sandstone of the Stainmore Coal Measures may be equivalent to the Basement Grit of the Durham Coalfield (Carruthers 1938).

The Communis zone carries several coals in the Central Pennine Coalfields but few in those of the Northern Pennines. In this respect the Stainmore Coalfield is more closely related to the northern province, whilst the Ingleton Coalfield (Ford 1954) shows close affinities with the Central Pennine Coalfields, and thus the boundary between the northern and Central Pennine Provinces lies between Ingleton and Stainmore, across the Craven Block, in a position similar to that occupied by the facies changes of the lower Carboniferous. Whilst the Lenisulcata and Communis zones are represented by typical non-marine lamellibranch faunas at Ingleton, no such faunas have been obtained at Stainmore.

The non-marine lamellibranchs from the Argill Shell Bed show unusual features, including a very wide variation from the long-tapered form *C.* cf. *antiqua* to the well-rounded cf. *Anthracosphaerium boltoni*. The less common shells such as those referred to ? *C.* cf. *rectilinearis*, *C.* cf. *rhomboidalis* and *Anthraconaia* spp. are somewhat unusual in an assemblage of this type and point to extreme variation, which may indicate mixing of faunas from two provinces. The apparent absence of the Lenisulcata zone in the Northumberland and Durham Coalfield

and very thin development in Cumberland (Trotter 1954) indicates a further contrast with the Central Pennine Province and might suggest a further analogy between the Northern Pennine Coalfield and Stainmore.

It is concluded that Stainmore was part of a northern land-mass during much of later Namurian times and the beginning of Ammanian times. Only in Modiolaris zone times is there clear evidence of uniformity of conditions in the spread of coalpeats into the Stainmore region.

I am indebted to Dr. J. Weir and Mr. M. A. Calver for their help in the identification of non-marine lamellibranchs, and Mr. W. Anderson for his permission to examine Goodchild's field slips and sections. I would also like to thank Professor L. R. Moore for his help and guidance throughout this work.

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GEOLOGY DEPARTMENT,
UNIVERSITY COLLEGE,
LEICESTER.

Structural Observations on the South-East Lizard [1]

By L. D. Sanders

Abstract

Geometry of the boundary of the serpentine in the south-east Lizard indicates that it is a sheet. The serpentine sheet rests on hornblendic gneisses and their migmatized equivalents ; the upper part of this basement represents a thrust-sole in which bodies torn from the base of the serpentine are enclosed. Coastal erosion of rocks beneath the serpentine tends to marginal collapse of the unsupported sheet, so that slipped masses may conceal its base.

I. Introduction

THE Lizard has interested geologists for many years and there is a wealth of published description which is summarized in the revised Memoir of H.M. Geological Survey explaining the New Series sheet 359 (Flett, 1946). Subsequent works dealing with Lizard geology have been contributed by Robson (1947), Dewey (1948), Hendriks, Scrivenor (1949), and Midgley (1951).

Those of Flett's conclusions with which this note is especially concerned are that (1) the serpentine is a plug or dome-shaped mass intrusive into the mica and hornblende schists which surround it, (2) the gneisses of Kennack and Erisey in the interior of the peninsula are later intrusions that have risen through the serpentine, and (3) serpentine masses up to several acres in extent are included in these gneisses.

The area discussed here is the south-eastern extremity of the Lizard peninsula. Almost all the main groups of igneous and metamorphic rocks displayed in the Lizard are to be found here, and with the omission of dyke-rocks their sequence as given by Scrivenor (1938, p. 385) is as follows :—

Kennack granite.
Kennack gneiss.
Gabbro.
Serpentine.
Hornblende schists and gneisses (of Landewednack and Cadgwith).
Man of War gneisses (of the Lizard skerries).
Oldest. Old Lizard Head Series.

The structural relations between the hornblende schists, the Kennack gneisses, and the serpentine are particularly well displayed in the south-east part of the Lizard ; this note refers mainly to these relationships.

[1] Published by permission of the Commissioner of Mines and Geology, Nairobi, Kenya.

II. Distribution of Serpentine

Topographically the southern Lizard is an almost flat platform bounded by sea cliffs which in places reach two hundred feet in height. The undulating surface rises gently inland to rather more than two hundred and fifty feet. It is dissected in the east by valleys at Pen Voose, Cadgwith, Poltesco, and Kennack. At the shoulders of the valleys an almost continuous escarpment can be traced at a height of about one hundred and eighty feet, and is often located by outcrops of serpentine. Small quarries have been opened in the serpentine at this level ; in a few of them the floor has been excavated to hornblende schists or gneiss. Below the escarpment outcrops of serpentine *in situ* are very rare, and it is clear from the nature of rock fragments in the fields that the valley floor is underlain by hornblendic gneisses and schists.

Between neighbouring valleys the interfluves stand at heights of more than two hundred feet. Much of this country, unlike the valleys, is poor agricultural land mantled with heavy clay which drains slowly. It is largely pasture and undeveloped heath where outcrops of serpentine are common.

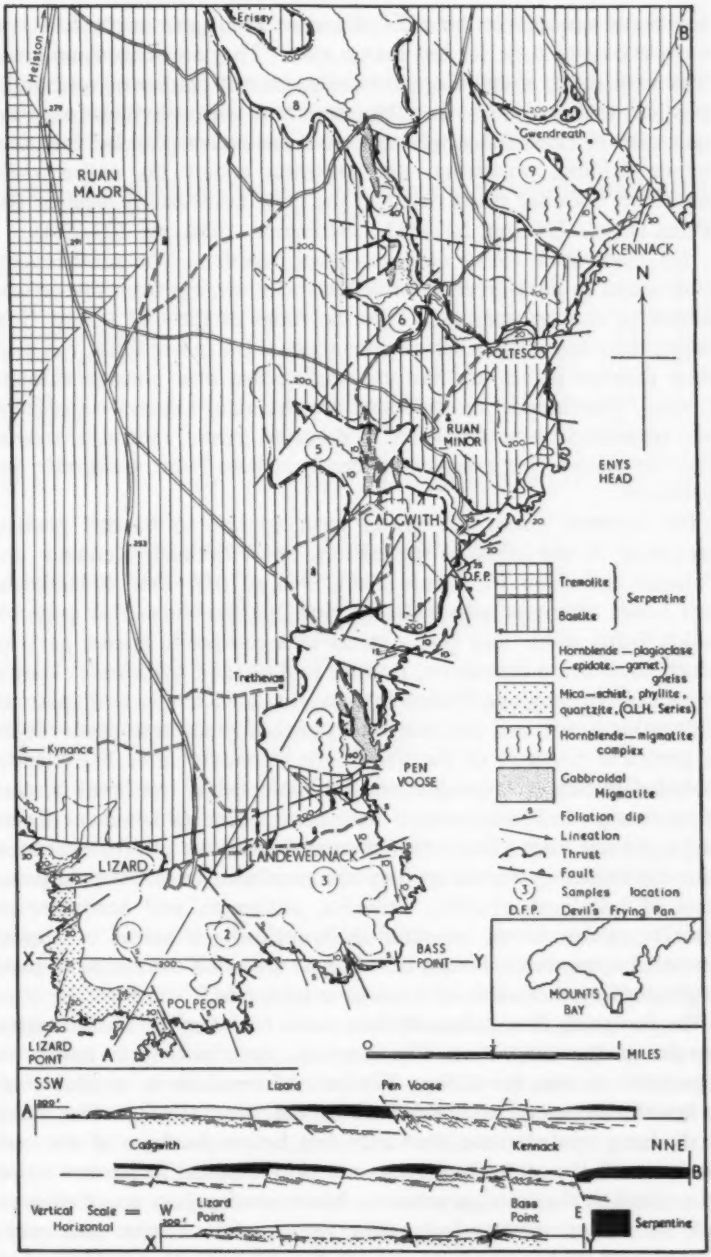
The manner in which the lower limit of serpentine exposures follows a sinuous contour along the valley sides indicates that the serpentine is a thin sheet whose contact with the rocks beneath is almost horizontal (Text-fig. 1). The maximum thickness of serpentine at the crowns of interfluves is of the order of seventy feet, reducing towards the edges of the valleys which have been eroded through it. Where the general elevation of the Lizard platform is below two hundred feet, as near Kennack, many small outliers of serpentine at the highest points represent the last isolated remnants of the sheet ; some are no more than a capping of residual serpentine boulders resting on gneisses beneath.

Along the coast from Kennack in the north to Pen Voose in the south the lower parts of the sea-cliffs show hornblende gneisses or banded hornblendic migmatites, serpentine often appearing at higher levels where the cliffs exceed one hundred and fifty feet in height. Elsewhere serpentine first outcrops some short distance inland where the rising slopes above the cliffs approach the two-hundred foot contour.

III. The Sub-Serpentine Formations

Consideration of the possible nature of rocks beneath the Lizard serpentine suggests reference to those exposed about its immediate margins in the south and east. These fall into three groups briefly described below :—

(i) *The Old Lizard Head Series.*—A series of metamorphosed



TEXT-FIG. 1.—Geological Map of the Lizard Serpentine from the Lizard to Kennack.

sediments exposed in the cliffs of Lizard Point and northwards, in a narrow coastal strip, for less than a mile. They are schists and granulites with mica, andalusite, sillimanite, garnet, cordierite, and anthophyllite (Tilley, 1937, p. 305), together with phyllites and thin quartzites. The mica-schists exhibit a distinctive crinkled foliation ; minor folding, puckering, and shearing affects the entire visible sequence. Similar rocks occur in the cliffs immediately west of Bass Point (Fox, 1890, pp. 327–333 ; Scrivenor, 1938, pp. 521–524).

(ii) *Hornblende-schists* (*Landewednack schists*).—The southern sea-cliffs stand in dark-green hornblende rocks varying from fine-grained schists to coarser gneisses. Like the rocks of the Old Lizard Head Series these hornblende schists sometimes show minor folds, but often their division planes are flat and undisturbed over considerable distances. Hornblende and andesine are the main mineral constituents and are sometimes accompanied by diopside, garnet, apatite, or sphene. Epidote often forms conspicuous bands at Bass Point, Cadgwith, and elsewhere.

(iii) *Kennack gneiss.*—A group term applied to banded gneisses appearing in the cliffs of the eastern coast between Kennack and Poltesco, and also at Pen Voose (Flett, 1946, p. 101). Dark hornblende-rich bands alternate with white or pink quartzo-feldspathic granulite which forms sheets and vein systems in a composite gneiss, parts of which show acute contortion, flowage folding, and *boudinage*. Biotite is commonly developed between adjacent hornblendic and quartzo-feldspathic bands, and it is likely that streaked concentrations of biotite in granitoid portions of the gneiss are secondary after hornblende. Included bodies of serpentine are abundant below the basal contact of the main ultra-basic mass ; they often occur as lenticular forms varying in size from a few inches to many feet across. At their contacts with the enclosing migmatite they are enveloped in a soft pale green mass of talc, anthophyllite, tremolite, antigorite, and haematite or limonite, which forms an outer shell enclosing a kernel of almost unaltered serpentine. Bodies of this type are often connected to their neighbours by thin veins of cross-fibre tremolite.

The foregoing description of those rocks found at the south-eastern margin of the serpentine, like previous descriptions, is based on exposures in the sea-cliffs. Further information is available at Cadgwith, Poltesco, and Kennack where the valley profiles have rarely been eroded more than fifty feet below the base of the serpentine, and the underlying rocks are only exposed in narrow strips determined by the drainage pattern. Most outcrops here are of massive pink or brown quartzo-feldspathic gneiss, often biotitic and interfoliated with darker bands containing hornblende. It is unlikely that these outcrops are representative of the underlying rocks since frag-

ments of hornblende gneiss are common in the soils of the fields and in the streams.

Table 1 shows the composition of samples each consisting of a hundred rock fragments (about three inches across) collected at random in the locations shown on the map (Text-fig. 1). The table indicates

TABLE 1.—CLASSIFICATION OF ROCK FRAGMENTS IN SOILS OVER SERPENTINE-FREE AREAS.

Sample Location No.	1	2	3	4	5	6	7	8	9
Hornblende gneiss	75	66	79	48	64	65	59	61	55
Granitoid gneiss .	4	6	2	28	17	19	16	14	30
Serpentine . .	10	15	17	10	12	9	21	16	11
Gabbro . .	—	2	—	8	6	2	4	6	2
Mica-schist . .	8	5	—	—	—	—	—	—	—
Other . . .	3	6	2	6	1	5	—	3	2
Total . . .	100	100	100	100	100	100	100	100	100

Sample locations. See map (Text-fig. 1) :—

1. Five hundred yards S.W. of Lizard.
2. „ „ „ S.E. „ „
3. Three „ „ South of Landewednack Church.
4. „ „ „ S.E. of Trethevas.
5. Half a mile W.S.W. of Ruan Minor.
6. „ „ West of Poltesco.
7. Poltesco valley. Eight hundred yards N.N.W. of Polstangey Bridge.
8. Five hundred yards S.S.E. of Erisey Farm.
9. Four hundred yards W.S.W. of Gwendreath.

over sixty per cent of hornblende gneiss fragments in the top-soils of these areas from which serpentine has been removed, compared with an average of over seventy per cent for the soils of the Lizard Landewednack area demonstrably underlain by hornblende schists and gneisses.

The low proportion of hornblende gneiss in the samples from Kennack and Pen Voose is correlated with a higher proportion of granitoid material. This appears to represent the quartzo-feldspathic component of a migmatite ; in optical features it resembles the granitoid sheets and bands of the Kennack gneisses, which vary in colour from white to pink depending on the amount of contained potash feldspar, and show porphyroblasts of both orthoclase and albite-oligoclase in a granoblastic aggregate of irregular sutured quartz and plagioclase. Strain shadows in quartz, and distortion or fracture of twin lamellae in plagioclase, are often evident. In these localities also fragmentary hornblende gneiss resembles the hornblendic bands in the Kennack gneisses, which typically consist of finely granoblastic hornblende and plagioclase, the former partly altered to biotite.

It is inferred therefore that in these valleys the rocks beneath the serpentine are mainly hornblendic gneisses, possibly similar to those south of Landewednack. Locally, the hornblende gneisses merge into hornblende-migmatites with granitoid sheets, which because of their superior resistance to erosion tend to outcrop and survive as fragments better than the hornblendic host.

IV. Structure

To the north the metamorphic and igneous rocks of Lizard are separated by a thrust zone from the Upper and Middle Devonian Series of South Cornwall. The dislocations, which locally contain contemporaneous intrusions of serpentine, have been shown to extend in a north-easterly direction to the Dodman and Start peninsulas (Hendriks, 1937, p. 336). Recent information obtained by submarine core sampling and seismic surveying confirms that a ridge of metamorphic rocks extends through the Eddystone reefs and is in contact with Devonian sedimentary rocks to the north (Hill and King, 1953, p. 17). This boundary may represent a continuation of the Lizard-Dodman-Start thrust zone.

The sheet structure of the south Lizard serpentine and the nature of its basement indicate that here also thrusting accompanied by large scale ultra-basic intrusion has occurred. A flat lineation produced by grooving and open corrugation of the hornblende schists trends N.N.W.–S.S.E. and is parallel to a mineral banding and shape orientation of pyroxene and tremolite in the serpentine, in which both enstatite and diallage crystals often have granulated margins and an augen form. Small lenticular or ellipsoidal bodies of serpentine enclosed in migmatites at Poltesco and Kennack have their major-axes lying in a north–south direction and are sometimes arranged in strings following the same trend. These features indicate differential movement in a N.N.W.–S.S.E. direction.

Joints dipping at between 40° and 70° either to the north or south are common in the serpentine. Their intersections with inclined north–south striking joints produces blocks which are pyramidal or gable shaped. A similar type of diagonal jointing is described by Scholtz (1953, p. 109) from above the Glarus Thrust, where it is attributed to tension in a thrust-mass which has moved under gravity.

Quartzo-feldspathic dykes striking approximately east-west and dipping to the north at between 40° and 70° do not appear to occupy faults which extend into the formations beneath the serpentine ; their consistent strike and dip direction suggests they occupy tension fractures which are a result of a northward relative movement of serpentine over its floor, in conformity with the translation sense of the

deeper Lizard boundary thrusts dated as Variscan by Hendriks (1937, p. 339).

Steep faults also affect both serpentine and basement. At Polpeor near Lizard Point hornblende schists are down-faulted against softer schists and granulites of the Old Lizard Head Series. Extension of the fault inland is marked by a low west-facing escarpment terminating where hornblende schists reappear on the westward side of the dislocation (Text-fig. 1). From here the contact between hornblende schists and the underlying Old Lizard Head Series extends northwards between the western coast and Lizard village. It is located at a height of about one hundred and fifty feet. The base of the hornblende schists is below sea level on the eastern side of the Polpeor fault, but the flat or gentle dip of the stratification planes between Polpeor and Bass Point, and the appearance at the foot of the cliffs of schists resembling those of the Old Lizard Head Series, suggests that the contact between the two series is near to sea level under this area (Text-fig. 1, section X–Y). It is likely that these formations continue to dip gently beneath the serpentine. Most foliation dips in the gneisses which exceed twenty degrees are connected with drag or local tilts near faults.

The southern boundary of the serpentine is determined by a zone of dislocations extending across the peninsula in an east-west direction beneath the villages of Lizard and Landewednack. The emergence of several northward-dipping faults can be seen in the cliffs on both sides of the peninsula, and the strike of foliation in the metamorphic rocks swings into parallelism with the fracture zone, where drags appropriate to normal faults down-throwing to the north are apparent.

Elsewhere small normal faults displace the base of the serpentine. One set trends roughly east–west, parallel to the southern serpentine margin and the other runs N.N.E.–S.S.W. Their emergence in the sea-cliffs is demonstrated by slickensiding, drag on the fault planes, and dolomitic or quartz veining.

V. Discussion

On the 1 in. Geological Survey map (New Series sheet 359, Flett and Hill, 1934) those inland areas where the formations beneath the serpentine are exposed are shown as granite-gneiss intrusive into serpentine. A marginal fringe of irregular branching intrusions of banded gneiss about the main granite-gneiss areas is also indicated in the Memoir (Flett, 1946, p. 99). The boundaries of the serpentine shown in Text-fig. 1 are generally similar to those on Sheet 359 with modification at Erisey, Poltesco, and Trethevas. In the latter locality excavations for the laying of a water main between Lizard and

Cadgwith during 1954 revealed a bedrock of hornblende gneisses with only occasional serpentine boulders. Rock fragments in the top soils confirm that much of this area is underlain by hornblende gneiss rather than serpentine.

The structural relationship of serpentine to its underlying rocks throws some light on the origin of the controversial Kennack gneisses. Before the publication of the first Lizard Memoir it was held that these represented stratified hornblendic rocks, possibly metamorphosed basic lavas and tuffs, which had been injected and somewhat softened by acid magma, after which they were intruded by serpentine (Bonney and McMahon, 1891, p. 497). These were interpreted by Flett (*op cit.*, p. 101) as flow-banded rocks representing the imperfect mixture of acid and basic magma.

The presence beneath the serpentine of hornblende gneisses preserving a generally low regional dip and (at Kennack) containing concordant granitoid sheets and interfoliations, suggest that these are the migmatitized equivalents of the Landewednack and Cadgwith hornblende schists.

Serpentine bodies found in both the hornblende schists and Kennack gneiss have been discussed with reference to the relative ages of these formations and the serpentine. Some workers took them for inclusions of serpentine in an intrusive gneiss (Lowe, 1901, 1902 ; Flett, 1946, p. 105). Others interpreted them as cross-sections of intrusive serpentine apophyses (Bonney, 1877, p. 901, and 1883, p. 22). The former view is supported not only by the contact effects between serpentine and the enclosing migmatite but also by the random orientation of mineral banding in separate masses. Where it can be seen this banding appears to bear no relationship either to the ellipsoidal shape of the serpentine inclusions or the foliation of the enclosing gneiss. These inclusions are believed to be serpentine removed from the lower levels of the sheet during differential movement.

Outcrops of serpentine of even several acres, such as are found inland, have been attributed to larger inclusions in an intrusive gneiss (Flett, 1946, p. 105). These are now explained as outliers of the serpentine sheet. A distinction between serpentine which has fallen from the faces of the sea-cliffs and that included in the gneisses is difficult since many large blocks are partly buried in the talus slops obscuring the base of the serpentine and its underlying formations.

An example of coastal landslipping can be seen immediately south of Enys Head where an arcuate depression some acres in extent has a floor about sixty feet below the neighbouring cliff summits. A mass of serpentine has slipped on a zone of weakness provided by faults parallel to the coast ; the slipped mass has been so little disturbed that its seaward face resembles a normal serpentine cliff. Available

structural information (Text-fig. 1) implies that a thickness of possibly seventy feet of serpentine here rests on metamorphic rocks, but the latter are covered by fallen rock.

The Devil's Frying Pan at Cadgwith indicates further the particular effects of rapid erosion of the underlying hornblendic gneisses. The serpentine has been undermined along a series of faults ; consequent collapse of the ultra-basic sheet left a conical depression with an arch of gneisses on its seaward side. Several blocks of serpentine perched on the top of the arch bear witness to the former seaward extension of the sheet from which they have fallen.

VI. Acknowledgments

I am indebted to the detailed description contained in H.M. Geological Survey Memoir " Geology of the Lizard and Meneage ", and also to Miss E. M. L. Hendriks for her contributions on South Cornish tectonics. To Professor R. M. Shackleton I am most grateful for helpful discussion and criticism.

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MINES AND GEOLOGICAL DEPARTMENT,
P.O. BOX 339,
NAIROBI, KENYA.

Biotitite in the Basement Complex of Southern Nyasaland.

By S. W. Morel

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Abstract

Recent work in the Middle Shire Valley has revealed a swarm of biotitite bodies emplaced in gneisses and granulites of the Basement Complex. The rocks of the Basement Complex are described briefly and referred to the Amphibolite and Granulite Facies of regional metamorphism. The field relations, distribution, and petrology of biotitite bodies show that they are a series of metamorphosed ultrabasic intrusions. An occurrence is described in which hydrothermal agencies have altered biotitite to vermiculite rock.

I. Introduction

THE Middle Shire Valley is a deep trough some twenty miles wide lying between the Kirk mountains to the west, the watershed of which forms the Anglo-Portuguese boundary, and the Shire Highlands to the east. The valley is part of the Nyasa Rift system and powerful normal faults of Rift type control the topography, which in consequence is rugged and dissected.

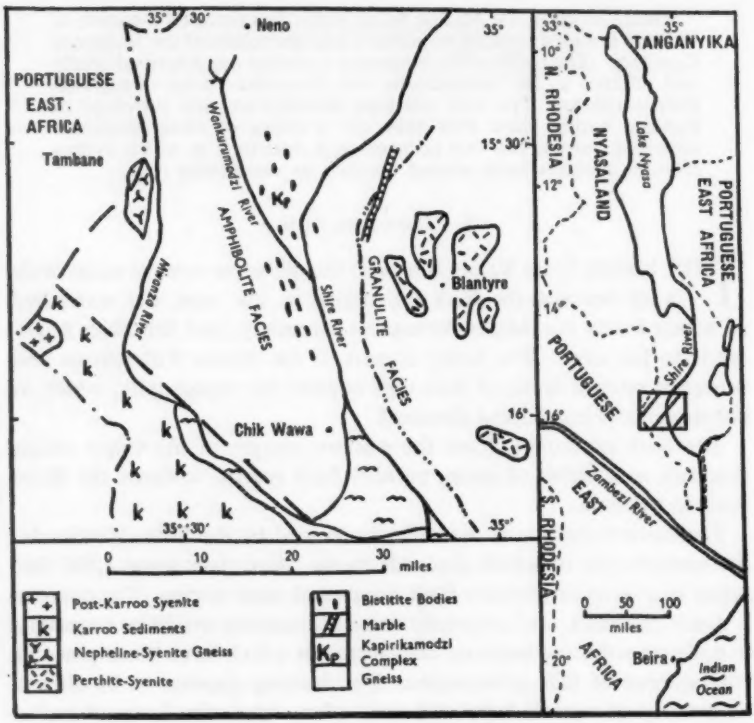
The Kirk mountains form the western margin of the valley which descends in a series of steep, parallel fault scarps, towards the Shire river to the east.

The eastern margin of the valley is formed by the Shire Highlands, the western side of which descends to the Shire river some 2,500 feet below in a series of irregular fault scarps and steep slopes. The country is much dissected, and extremely detailed mapping would be necessary in order to solve the intricate displacements which have taken place in consequence of Rift movements. The faulting appears to be almost exclusively of normal type and very often takes the form of strike faults.

Exposures of the crystalline rocks of the Basement Complex are good, although tall grass hampers observations until after the bush fires of July and August. The strike of the Basement Complex gneisses trends from N.N.E. in the northern part of the area, to N.N.W. in the southern half and their dip is westwards at about 50°. These strike directions have controlled the development of the main Rift Valley faults and also the course of the Shire River which follows the fault pattern, flowing S.S.W. in the northern and S.S.E. in the southern parts of the area. The physiography and structure of this area have been described by Dr. F. Dixey in a number of papers (Dixey 1925, 1926, 1946).

II. The Basement Complex in the Middle Shire Valley

The Basement Complex in the Middle Shire Valley can be separated into two divisions on the basis of metamorphic grade. In the eastern portion of the valley towards the Shire Highlands, rocks of the Granulite Facies are developed. The central and western parts of the valley are occupied by rocks of the Amphibolite Facies (Text-fig. 1).



Text-fig. 1.—Geological sketch map of the Middle-shire valley showing the location of the biotitite swarm.

(*a*) *Shire Highlands area*

The dominant rock type developed in the Shire Highlands is a banded hypersthene granulite which strikes N.N.E. to N.N.W. and dips westwards at about 50°. It is a mesotype blue-grey rock when fresh, with finely alternating mafic and felsic bands and many concordant pegmatites. It is allotriomorphic-granular with an even grain, the individual crystals seldom exceeding 5 mm. in diameter. The mineralogy of the rock is identical with the Intermediate Division of the Charnockite Series of Sir Thomas Holland (1900). Hypersthene is always

present, and is usually weakly pleochroic. Pale green pleochroic diopside and strongly pleochroic green hornblende are usually present. Potash feldspar is always cryptoperthitic, plagioclase varies between mid-oligoclase and mid-andesine and is often untwinned. Myrmekite is common. Grey quartz forms about 10 per cent of the rock and has a peculiar lobate form ; in thin sections it is seen to contain numerous lines of dark inclusions and to have undulatory " strained " extinction. Anhedral crystals of titaniferous iron-ore are always present. Biotite is often common as a reaction product around iron-ore.

Bands and schlieren of a melanic hypersthene-bearing granulite are developed widely in the mesotype granulite. The melanic rock corresponds to the Basic Division of Holland's Charnockite Series. The hypersthene is a more strongly pleochroic variety than in the mesotype rock, whilst hornblende and diopside are present in larger amounts. Biotite is fairly common. Potash feldspar is absent and the plagioclase varies between mid-andesine and acid labradorite. The iron ore is magnetite, whilst pyrite and pyrrhotite are often present. The melanic hypersthene-granulite sometimes has discordant relationships to the mesotype rock and possibly represents a series of pre-metamorphic basic intrusions.

Subordinate garnet-hornblende-plagioclase-gneiss forms occasional discontinuous bands in the hypersthene-granulites, and a dolomitic marble horizon, more than twenty miles long, and of variable thickness lies close to the boundary between the Granulite and Amphibolite Facies in the northern half of the area (Text-fig. 1).

Prior to the regional metamorphism that gave the hypersthene-granulites their present characters, they were intruded by igneous rocks, now represented by pyroxenites of websterite type and by perthite-syenites. The latter contain basic dykes which have been metamorphosed and thus confirm that the hypersthene-granulites are of metamorphic origin.

(*b*) *Central and Western parts of the Middle Shire Valley*

The commonest rock type present in the Central and Western parts of the Middle-Shire valley is a biotite-plagioclase-gneiss with varying amounts of green hornblende. Pale green diopside is usually present and the feldspars are oligoclase with a small amount of perthite. Quartz forms lobate crystals with undulose extinction. Sphene is a common accessory. The biotite-gneiss often shows signs of alkali metasomatism in the development of large crystals of sub-idioblastic perthite. By an increase in hornblende the rock passes into hornblende-biotite-gneiss, in which the feldspar is usually andesine and in which garnet is often developed. Narrow bands of garnet-hornblende-epidote-gneiss are sometimes found. Pyroxene-granulites are rarely

developed and do not often contain hypersthene. Some bands have the appearance of highly metamorphosed arkoses and in the extreme west, near to Tambane, quartz-schists are present (Cooper, 1952, Bloomfield, 1952).

A number of bodies of biotite-pyroxenite have been found in this area and appear to be the equivalents of the websterite-pyroxenites found in the Granulite Facies. Intrusions of quartz-microsyenite are widespread as small bodies.

Dyke-like bodies of basic granulite have been found occasionally in the biotite and hornblende-gneisses and are possibly related to those found in the Granulite Facies.

The biotitite bodies described in the following section form a distinct group in the Basement Complex and pre-date the regional metamorphism.

Cooper (1946, 1952, 1955) has described nepheline-syenite-gneiss from Tambane which is intrusive into Basement Complex gneisses. The nepheline-syenite-gneiss contains zircon and monazite which have been the subjects of age determinations, by radiometric methods, by Professor E. S. Larsen. The results of these determinations give an age of approximately 550 million years (Tilley, 1954).

Cooper considers the nepheline-syenite-gneiss to be younger in age than the regional metamorphism which has given the Basement Complex its present character. He correlates the Basement Complex with the Mozambique System of Holmes (1951) and regards it as being Middle Pre-Cambrian in age (Cooper, 1955).

Bloomfield (1954) described similar nepheline-syenite-gneiss from the Port Herald Hills and thinks that it was intruded during the waning stages of the regional metamorphism. Thus the upper limit for the age of the regional metamorphism is 550 million years and it may be of considerably greater age.

III. (*a*) Biotitites

(i) *Nomenclature.*—Washington gave the name " biotitite " to a rock composed almost entirely of black mica, found as cognate inclusions in an agglomerate at Villa Senni near Rome. Larsen and Pardee described a rock mass composed of 98 per cent biotite and 2 per cent accessories, mainly apatite, for which they suggested the name " glimmerite ". Johannsen (1937) preferred the latter name on account of the two " ites " in " biotitite ".

The term " biotitite " as employed by the writer, denotes a rock composed essentially of dark mica, with or without accessory amounts of pyroxene, amphibole, apatite, and iron ore. The term has not been restricted to igneous rocks and is here applied to rocks of metamorphic origin. When pyroxene or amphibole attain the status of essential

constituents but do not exceed 50 per cent of the rock, the appropriate mineral name is used as a prefix to " biotitite ". If the pyroxene becomes dominant, the term " biotite-pyroxenite " is employed.

(ii) *Field relations.*—Bloomfield (1952) in his description of the geology of the Majete area, refers to " pyroxene-biotite-schists " which he described as follows : " Between the Wamkurumadzi river and the Mwambezi stream there is a strip of country about five miles wide which contains many bands and lenses of pyroxene-biotite-schist. This strip continues to about four miles north-west of Chikwawa Boma. The bands and lenses of schist average about 400 yards in width and strike parallel to the surrounding biotite-hornblende and pyroxene gneisses. The proportion of biotite to pyroxene varies, but there is usually more biotite than pyroxene in the rocks . . ."

The specimens collected by Bloomfield are coarse-grained schistose hypermelanic rocks. The individual mica flakes form books up to 1 cm. in diameter and 1 mm. in thickness, and have a fairly regular foliation. Mica from one of these specimens is a phlogopite : $\beta\ (=\gamma) = 1{\cdot}606$.

The biotitite bodies extend from the area described by Bloomfield, at least as far as the Mlindi biotite-pyroxenite intrusion, described by Ashley (1951), some twenty miles to the north. As work progresses in this area, many more such bodies will probably be found. They are also known at a few localities on the east side of the Shire River.

The biotitite bodies are elongated along the strike of the enclosing gneisses, to about five times their width, which varies from thirty to four hundred yards, although some dyke-like and plug-like masses occur. Contacts with the gneisses are usually concordant, but close examination reveals small scale discordances and intrusive junctions. The boundaries of the bodies often form loci for faults and it is consequently difficult to find evidence of an intrusive origin.

(iii) *Petrography and Mineralogy.*—The biotitites are coarse-grained mica schists with a fairly regular foliation. The mica forms books usually about 2 cm. in diameter and 5 mm. in thickness but patches with a smaller grain size are often found. It is often partly altered to vermiculite in the smaller bodies.

The quantity of pyroxene or amphibole varies considerably, seldom reaching more than a few per cent, but in some cases, green pyroxene becomes prominent and the rock grades into pyroxene-biotitite.

Refractive index measurements of basal sections of phlogopite from a faulted biotitite mass 1½ miles downstream from the Wamkurumadzi bridge on the Blantyre-Mwanza road, gave $\beta\ (=\gamma) = 1{\cdot}603$.[1] This

[1] Refractive indices determined by Leitz-Jelley micro-refractometer, estimated accuracy $\pm$ 0·002.

rock is entirely formed of phlogopite in crystals of about 2 cm. diameter and is well foliated.

An outcrop on the east side of the Shire River some eight miles N.E. of Chikwawa, lies near to the boundary between the Amphibolite and Granulite Facies. The rock is formed of small books of phlogopite about 5 mm. in diameter and 0·5 mm. in thickness. The outcrop is about 150 feet wide striking parallel to the foliation of the surrounding pyroxene granulites. Thin sections show that this biotitite consists of some 95 per cent phlogopite, $\beta\ (=\gamma) = 1{\cdot}598$, $\gamma - \alpha = 0{\cdot}045$, with 2 V small and negative ; Z = Y = deep brown, X = colourless. The mica flakes are usually perfectly euhedral but bent flakes are sometimes present. A few crystals are partly altered on their boundaries to anthophyllite and orthoclase, which lobe into the mica. Relict crystal structure of the mica is sometimes apparent in the amphibole. The anthophyllite has a composite appearance, with some portions extinguishing irregularly, and enclosing blebs of orthoclase in optical continuity with each other ; orthoclase also rims the anthophyllite, which is colourless and non-pleochroic and forms anhedral crystals. Extinction is straight, birefringence moderate, $\gamma - \alpha = 0{\cdot}017$ and 2V is large and positive. Crystals of very pale green tremolite occur with the anthophyllite as anhedral crystals, with 2 V large and negative.

The reaction involved in the alteration of the phlogopite as observed in thin sections is :

(1) Mg-phlogopite + silica → anthophyllite + orthoclase + water and is probably a stage in the reaction :—

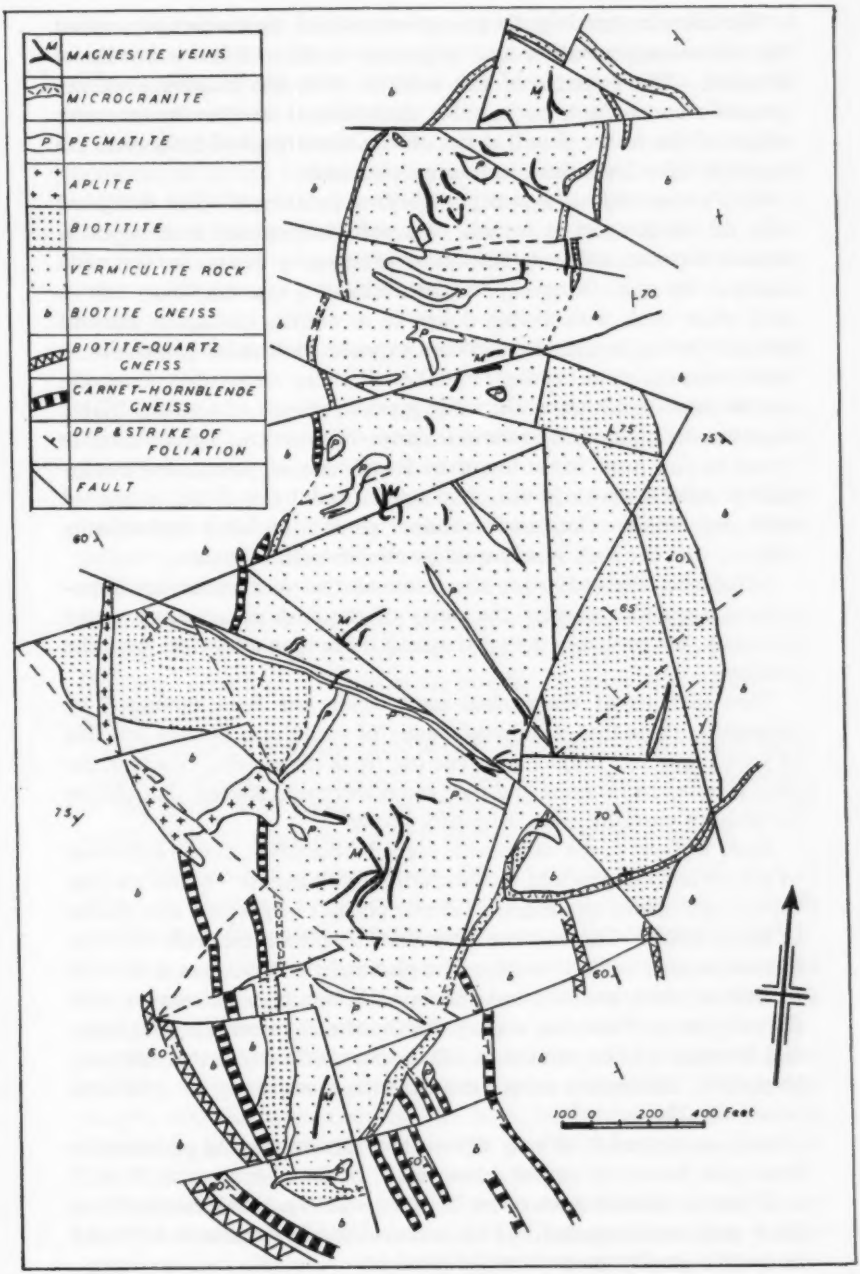
(2) Mg-phlogopite + silica → enstatite + orthoclase

Ramberg (1952) indicates that reaction (2) takes place, with increasing metamorphism at the boundary between the Amphibolite and Granulite Facies.

III. (*b*) The Kapirikamodzi Complex

(i) *Field relations.*—The writer has recently discovered an occurrence of biotitite which has been largely altered to vermiculite rock. Due to its potential economic value, it was surveyed on a scale of 1:3,000 (Text-fig. 2).

An elongated low hill lies some three miles W.N.W. of the road bridge over the Shire River at Mpatamanga Gorge at Lat. 15° 41′ 49″ South and Long. 34° 40′ 50″ West. It is conspicuous as it is almost entirely devoid of trees and has thus been named " Kapirikamodzi " (" The small hill that stands alone ") by the local Nyanja people. It shows up as a light coloured patch near to the Blantyre-Mwanza motor road on Aerial Photograph 5302, series 82A/9/N.Y. issued by the Directorate of Colonial Surveys. The hill is 4,000 feet long and about 1,500 feet wide with its long axis orientated north–south.



TEXT-FIG. 2.—Geological map of the Kapirikamodzi Complex.

The complex consists of a core of vermiculite rock which is ramified by microcline-pegmatites and magnesite veins, and has a border of biotitite. The contacts of the complex with the country rock are generally concordant, but notable discordances confirm the intrusive origin of the mass. Small dykes of a metamorphosed basic rock are found at a few localities in the vermiculite rock.

(ii) *Petrography and Petrology*: *The vermiculite rock*.—The elongated core of the complex is formed of a soft decomposed rock which is seldom exposed, and only betrays its presence by minute golden mica flakes in the soil. When exposed naturally, it is a mottled rusty-brown and white rock with visible flakes of a whitish micaceous mineral about 0·5 mm. in diameter. When exposed by trenching, the rock is seen to consist almost entirely of flakes of golden vermiculite of varying size in some localities, whilst other portions consist of a yellow friable clayey material, formed by the breakdown of the mica. The vermiculite varies in size from flakes less than 1 mm. in size, to massive honey-yellow crystals up to 20 cm. in diameter and 5 cm. thick, associated with pegmatites. Occasional residual patches of black hydrobiotite indicate that the rock was formed by alteration of biotitite.

Magnesite, derived from alteration of the vermiculite by atmospheric agencies, cements the parts of the rock which are exposed naturally, but probably does not extend more than a few feet from the surface.

Thin sections of the surface rock which has been cemented by magnesite, show that it consists mainly of vermiform fibrous lamellae of vermiculite in a cryptocrystalline matrix of magnesite. Voids in the rock rimmed by limonite and pale green antigorite suggest that olivine or perhaps enstatite were originally present.

Basal sections of the vermiculite are sub-hexagonal, due to corrosion of the crystal margins and the formation of magnesite. Some are pale brown and others colourless. Tabular crystals of goethite are present in many flakes. The basal sections are non-pleochroic with very low birefringence. $-2V$ is small. The plane of the optic axes is parallel to 010 in most sections but the crystals are only orientated with difficulty as corrosion has usually destroyed recognizable crystal faces, and it appears to be parallel to 100 in some sections, so that talc may be present. Refractive index measurements gave $\beta\,(=\gamma) = 1{\cdot}552$ and $\gamma - \alpha = {\cdot}02$.

Sections normal to 001 are fibrous and show a varying pleochroism from pale brown to almost colourless. In thinnish sections $X < Y = Z$ but in thickish ones often $X > Y = Z$. In each case the fibres show positive elongation. This vermiculite is insoluble in HCl and its specific gravity varies from 2·32 to 2·34.

Sub-idiomorphic crystals of very pale green tremolite occur in the

rock matrix. It is fairly common although unevenly distributed. Absorption is weak with Z = pale blue-green, Y = pale green, X = pale yellow green, $Z \wedge c = 19°$, $-2V$ is very large, $\alpha = 1{\cdot}630$. Prismatic sections are always length slow.

Anthophyllite (gedrite ?) is also present but is rarer than tremolite. It forms colourless crystals with grains of iron ore in the cleavages. $-2V$ is very large, and its R.I. approaches 1·63. It has positive elongation with straight extinction. In grains X = brownish, Y = brownish, Z = pale green, but in thin sections it shows no pleochroism.

Very pale green pigeonitic diopside is also present in the matrix as anhedral crystals. $Z \wedge c = 34°$, $\gamma - \alpha = {\cdot}02$.

Chromite as octahedra up to 0·5 mm., and apatite are the only accessory minerals.

The magnesite matrix is cryptocrystalline and forms some 40 per cent of the rock. It is undoubtedly secondary in origin, formed by the alteration of magnesian silicates.

The optical properties of the vermiculite are very similar to those described by Gevers (1948) from Loolekop, Transvaal, for golden yellow vermiculites derived fron phlogopite.

The vermiculite in the complex is of three main types :—

(*a*) Black hydrobiotite, derived from weathering of biotitite at the contact of the vermiculite rock with the surrounding biotitite. Exfoliation varies from 8–20 times the original thickness when heated in a spirit flame.

(*b*) Coarse grained pegmatitic honey-yellow plates occurring in books 2 inches thick and from 2 inches to 9 inches in diameter with exfoliation of the order of 20 times. This type only occurs at the margins of quartz-feldspar pegmatites which ramify the vermiculite rock.

(*c*) Fine grained golden-yellow flakes varying from 0·05 to 0·25 inches in diameter, which exfoliate from 10–30 times their thickness on heating. This type forms the main mass of the vermiculite rock.

The biotitite.—The vermiculite rock is almost entirely surrounded by a zone of biotitite. In the north and south parts of the intrusion, this takes the form of a zone from ten to a hundred feet wide.

The central part of the vermiculite rock is flanked by large masses of biotitite. The eastern flank is formed by an arcuate hill 2,000 feet in length, 500 feet wide and 300 feet high, whilst the western flank is formed by a much smaller mass. The dips of the foliation vary with the fault pattern.

The biotitite is a coarse-grained hypermelanic rock in which mica forms books up to 20 mm. in diameter and 5 mm. in thickness. Green pyroxene and amphibole are often associated with the mica, but only very rarely do they comprise more than 10 per cent of the rock. Albite

is occasionally present. Its maximum extinction angle in sections normal to 010 = 20°, $\alpha = 1{\cdot}528$, $\beta = 1{\cdot}532$.

The biotite is a phlogopite. $-2V$ is small, absorption weak, Z = pale brown, Y = paler brown, X = colourless. The R.I.'s of basal sections for three specimens gave $\beta\,(=\gamma) = 1{\cdot}611, 1{\cdot}610, 1{\cdot}606$. Birefringence is strong $\gamma - \alpha = {\cdot}045$. The flakes are often bent but only rarely broken.

Green diopside often replaces part of the phlogopite, into which it lobes and is colourless or very faintly green in thin sections. $Z \wedge c = 37°$, $\beta = 1{\cdot}666$, $\gamma - \alpha = {\cdot}025$. The elongation is positive, dispersion $r < v$ weak. Twinning is common on 100. These data indicate about 20 per cent of clinoenstatite in the diopside molecule (Winchell, 1948).

Tremolite often mantles the diopside and is also present in patches inside it. It is colourless to very pale green, faintly pleochroic, with a negative sign and positive elongation, $\beta = 1{\cdot}626$, $\gamma = 1{\cdot}636$, $\gamma - \alpha = {\cdot}019$, and $Z \wedge c = 19°$. It is sometimes altered to a colourless fibrous mineral.

Orthoclase is a constant companion of the diopside and tremolite, as anhedral patches in the crystals or occurring on their boundaries. Its occurrence is explained by reactions (1) and (2).

The contacts of the biotitite with the country rock are generally more or less concordant, except in the south part of the complex, as shown on the map (Text-fig. 2).

The basic dykes.—At a number of localities in the vermiculite rock, narrow dykes of a submelanic fine-grained rock are found, marked by lines of float. Thin sections show about 40 per cent of green hornblende forming sub-idioblastic crystals up to about 1 mm. in size, with strong pleochroism, Z = deep olive-green, Y = olive-green, X = pale yellow-green. The rest of the rock is anhedral oligoclase, with a composition near to $Ab_{80}An_{20}$, and accessory amounts of magnetite and apatite. This rock is a basic dyke which has recrystallized under regional metamorphism of Amphibolite Facies grade thus proving that the host rock has similarly suffered these conditions.

Pegmatites, aplites and microgranite.—The vermiculite rock is ramified by numerous quartz-microcline pegmatites with highly developed graphic textures. They are coarsely crystallized with microcline crystals up to 20 cm. long. Patches of vermiculite are found in books up to 20 cm. in diameter and 5 cm. thick, and are no doubt formed by the interaction of pegmatitic material with the ultramafite. Only one pegmatite and one microgranite dyke were seen in the biotitite.

The aplites and microgranites are typical oligoclase-microcline-quartz rocks with myrmekitic textures. They contain varying amounts

of muddy brown biotite partially altered to a strongly pleochroic blue-green to pale-green hornblende ; these have the appearance of being xenocrysts picked up from the biotitite during their intrusion. The accessory minerals of these rocks are subhedral sphene, apatite, and a little iron ore.

Magnesite veins.—The vermiculite mass is ramified by veins of white porcellanous magnesite. They vary from a few millimetres to 50 cm. in width and commonly occupy the margins of pegmatite and aplite dykes which they intersect. They are also present in veins and fissures where pegmatites are absent.

In thin sections the magnesite is seen to be mainly cryptocrystalline with a few larger crystals. The white rock is about 90 per cent $MgCO_3$, 5 per cent $CaCO_3$, with 5 per cent insoluble residue. It has a hardness of 6·5, as opposed to the normal 3·5 to 4·5. Bassett (1954) has recorded porcellanous magnesite with a hardness of 7·5 from Tanganyika. Some of the magnesite veins carry corroded flakes of golden brown vermiculite, picked up by the solutions which precipitated the magnesite.

The magnesite veins represent the latest vein rocks formed. It is probable that they were precipitated by circulating ground waters as there are no other minerals crystallized with the magnesite. They are colloform in texture, and undoubtedly of low temperature formation, and are not found in the biotitite.

(iii) *Origin of the vermiculite.*—Gevers (1948) in discussing the origin of the Loolekop vermiculite, has proved by a series of chemical analyses, that it has formed by hydration and removal of potash from phlogopite and biotite. In view of the similarity of the Kapirikamodzi vermiculite to that of Loolekop and the fact that the Kapirikamodzi vermiculite-rock grades into biotitite, and contains relics of hydrobiotite, it is certain that this process is responsible for the formation of the vermiculite.

The evidence at Loolekop suggests that the formation of vermiculite and hydrobiotite is related to the present land surface and is due to ground water, as the vermiculite passes progressively downwards into less highly hydrated varieties and finally into phlogopite. However, Gevers lists some features at Loolekop which cannot be explained adequately on a basis of ground water percolation. They are :—

(1) Fresh unaltered phlogopite is found side by side with fully hydrated high-grade vermiculite close to the surface of the ground.

(2) The association of phlogopite and vermiculite in depth, side by side, with no reference to penetration by surface water.

(3) Where residual patches of phlogopite are surrounded by vermiculite near to the surface, both minerals are traversed by magnesite veins indicating the infiltration of an abundance of meteoric water

down from the surface. There is no evidence that vermiculitization progressed along veins and fractures filled with downward percolating surface water.

(4) In several cases phologopite has been altered to vermiculite adjacent to narrow veinlets of apatite rock, indicating that magmatic fluids were responsible for the alteration.

(5) Around apatite patches and veins and stringers of feldspar in bodies of only slightly hydrated varieties of vermiculite (hydrobiotite, etc.), the latter are transformed into highly or fully hydrated types of vermiculite, again indicating the operation of magmatic fluids.

(6) Flakes of fully hydrated yellow vermiculite are often completely enclosed in "pegmatitic" diopside showing no alteration by weathering.

Thus at Loolekop there is evidence for formation of vermiculite by weathering as well as by magmatic agencies.

At Kapirikamodzi, as stated earlier, the vermiculite rock carries numerous quartz-feldspar pegmatities, whilst the adjacent biotitite does not. Since the vermiculite rock is surrounded by biotitite and there are residual patches of biotitite in the former, it is highly probable that the vermiculite rock was originally biotitite. The occurrence of pegmatites in the vermiculite rock, but not in the biotitite, strongly suggests that the pegmatites are responsible for the formation of the vermiculite. This contention is supported by the "pegmatitic" vermiculite which has formed adjacent to pegmatite veins.

Evidence for decrease in vermiculitization with depth, as at Loolekop, is at present lacking. Weathering is, however, responsible for the formation of magnesite in the rock exposed at the surface, and circulating ground waters probably precipitated the magnesite veins.

IV. Origin of the Biotitites.

The mineralogy of the biotitites as described in the previous section, shows that they are rich in magnesia, comparatively poor in lime and very poor in silica and alumina. The iron ore contains chromium and pseudomorphs, possibly of olivine, are present. The composition of the phlogopite in the biotitite is that typical of peridotites and other ultramafites (Heinrich, 1946).

The field relationships show that they are intrusive rocks, and the occurrence of metamorphosed basic dykes in the Kapirikamodzi vermiculite-rock shows that it has suffered high-grade regional metamorphism. It is very probable, therefore, that the Middle-Shire biotitites are a series of metamorphosed peridotites or serpentinites. In this connection it is significant that Benson, Pratt and Lewis and others, quoted by Turner and Verhoogen (1951), have described peridotite and serpentinite intrusions from 100 yards to 1 mile in

length occurring in swarms which may consist of hundreds of sub-parallel masses following the axes of broadly contemporary fold-mountain chains. The distribution and intrusive characteristics of the Middle-Shire biotitites are remarkably similar to those of these ultrabasic intrusions.

The incipient alteration of the phlogopite of the biotitites to orthoclase and anthophyllite, and the presence of pigeonitic-diopside, show that the grade of metamorphism is close to Granulite Facies conditions. Lack of water is a characteristic of these conditions (Turner, 1948, p. 102).

The alteration of peridotite to biotitite requires addition of potash, alumina, and water. The source of these components may have been the venitic pegmatites which were produced in the country rocks during the regional metamorphism. However, the lack of pegmatites in the biotitites suggests that metasomatism took place by diffusion. The general lack of water in rocks undergoing metamorphism of Granulite Facies grade suggests that it may have been a "dry" type of diffusion, but in the absence of evidence the nature of the metasomatism must be left an open question. The well developed foliation of the biotitites shows that directional forces were present during the crystallization of the phlogopite. Such forces would aid diffusion and promote chemical reactions.

The pegmatite and aplite veins and the microgranite dykes that intrude the vermiculite-rock at Kapirikamodzi are quite distinctly younger than the regional metamorphism, and cannot have been the cause of the alteration of the original ultramafite to biotitite. Their contacts are sharp, and the microgranite dyke in biotitite on the eastern flank of the complex shows no signs of metamorphism. The coarse grain size and graphic textures of the pegmatites indicates that they crystallized under hydrothermal conditions. These late pegmatites are the cause of the vermiculitization of the biotitite.

V. Conclusion

The biotitite bodies of the Middle-Shire valley are a swarm of ultrabasic intrusions which have been metamorphosed under conditions of Upper Amphibolite-Granulite Facies grade regional metamorphism. As a consequence of the metamorphism, influx of potash, alumina and water caused recrystallization of the parent rock with the formation of biotitite. Subsequent intrusion of quartz-microcline pegmatites into the Kapirikamodzi biotitite was responsible for its vermiculitization.

VI. Acknowledgments

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GEOLOGICAL SURVEY DEPARTMENT,
P.O. BOX 27,
ZOMBA,
NYASALAND.

Some Devonian Fish Remains from North Central Vestspitsbergen

By D. L. Dineley

Abstract

Fish remains from the Wijde Bay Series of the Wijdefjorden area include (1) pteraspids, not previously recorded from so high an horizon, which appear to bear sensory canals upon the exterior surface of the ventral disc ; (2) an *Asterolepis*, and (3) rhizodontid scales, resembling those of *Holoptychius*. A very large antiarch from an unknown horizon is also recorded.

In the course of the Cambridge Spitsbergen Expeditions of 1949 and 1951 a few Devonian vertebrates were collected. Through the courtesy of Mr. W. B. Harland the writer has been allowed to examine the specimens and, at the suggestion of Professor A. Heintz, of Oslo, has written the following notes. To these gentlemen the writer tenders his thanks.

As is usual, the specimens are largely fragmentary and preserved in coarse-grained matrices—ferruginous, pellety sandstones or quartzites. Most of the fossils collected appear to come from the Wijde Bay Series, the vertebrates of which are perhaps, as Føyn and Heintz (1943, p. 32) note, rather more scarce and fragmentary than in the lower subdivisions of the Devonian in Vestspitsbergen. The upper Middle Devonian age of the Wijde Bay Series is indicated by an assemblage of large arthrodires (*Heterosteus*), antiarchs (*Asterolepis*), the very common psammosteids and rhizodontid (Crossopterygian) scales.

The collections made by the Cambridge expeditions include fragments of psammosteids, arthrodires, antiarchs and the pteraspids and *Holoptychius*-like scales described below. The *Holoptychius*-like scales have not been previously recorded and the pteraspids are apparently new, though Føyn and Heintz (1943, p. 34, fig. 14) mention fossils which they regard as aberrant pteraspidomorphs related to the pteraspids, from the Wijde Bay Series on the west coast of Wijdefjorden. These fossils do not appear greatly to resemble the pteraspids described below, but their presence in the upper Middle Devonian Wijde Bay Series calls for further investigation into the palaeontology of the series.

Description of Specimens

Class AGNATHA

Sub-class Pteraspidomorphi

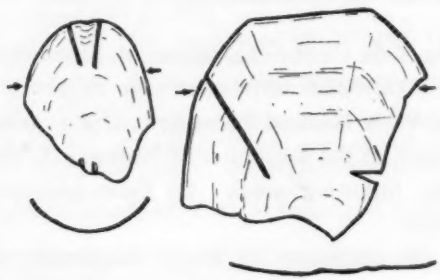
Order *HETEROSTRACI*

Family PTERASPIDAE

Pteraspids

(Text-figs. 1 and 2)

A single piece of dark siltstone (No. H 32) [1] contains two fossils, each being the external impression of the anterior part of a pteraspid ventral disc. The smaller of these (No. H 5167) is 20 mm. broad and



1 2

Text-fig. 1.—Pteraspid (No. H 5167), anterior part of central disc, × 1. Wijde Bay Series, " Fish Point," Tage Nilssonfjellet, Wijdefjorden.
Text-fig. 2.—Pteraspid (No. H 5168), anterior part of central disc, × 1. Wijde Bay Series, " Fish Point," Tage Nilssonfjellet, Wijdefjorden.

16 mm. long, is notably rounded in outline, and possesses a very small, shallow anterior median notch. The plate is moderately convex, attaining a depth of 7·7 mm. at its broken margin. The ornamentation is poorly preserved, but appears to be extremely fine. Distinct fine ridges in the impression represent the post-oral canals, indicating sharp, narrow grooves on the outer surface of the actual plate. To the writer's knowledge such grooves are unusual, the sensory canals having been found hitherto only within the actual tissue of the plate. Each groove is about 6 mm. long, but the two do not appear to form the usual unbroken V. Two further fragments of similar grooves lie close to the axis of the plate at its broken edge. They may possibly be disconnected portions of the post-oral canals, produced far back across the plate ; in *Rhinopteraspis dunensis* the post-oral canals extend backwards over two-thirds of the length of the disc. Since the grooves are so near to the axis of the plate it is not very likely that they are fragments of the longitudinal canals.

[1] Registered number in the Sedgwick Museum, Cambridge.

The larger specimen (No. H 5168) is extremely flat, with a straight anterior margin, and no indication of a median notch. The ornamentation is again extremely fine though poorly preserved. The anterior end of the left longitudinal canal is preserved, again as a fine ridge, extending some 15 mm. from the antero-lateral margin of the plate in a postero-medial direction (see Text-fig. 2). The post-oral canals are not represented, and there is no trace of the right longitudinal canal.

Since the two specimens described above are fortunately of the same parts of similar plates they are easily compared, and it appears unlikely that they belong to the same species. They cannot readily be referred to known species and the presence of sensory canal grooves, as distinct from lines of mucous pores, on the outer surface of the plate seems to be a new feature. The emergence—at least partially—of the sensory canal system in grooves on the outer surface of the plate may possibly be a late development in the evolution of the Spitsbergen pteraspids. It would appear to be a feature not developed in the European late pteraspids as far as is known.

Geological horizon and locality.

Wijde Bay Series; from a bone-bed outcropping about half way up the south-eastern spur of Tage Nilssonfjellet [1], Wijdefjorden (" Fish-Point "). The presence of pteraspids in the Wijde Bay Series is certainly surprising, for these beds are, upon good evidence (see Føyn and Heintz, 1943, p. 48), placed in the upper Middle Devonian. It is, of course, possible that the fossils are re-sorted specimens derived from a lower horizon. Pteraspids are known in horizons in Vestspitsbergen as high as the Lykta Division of the Wood Bay Series, but as Føyn and Heintz remark (1943, p. 45), they are not known with certainty from deposits younger than Lower Devonian. Further specimens are needed from the " Fish Point " locality; the other fossils obtained from it include, apart from the crossopterygian scales described below, nothing unusual for the Series.

Class **PLACODERMI**

Order *ANTIARCHI*

Family ASTEROLEPIDAE

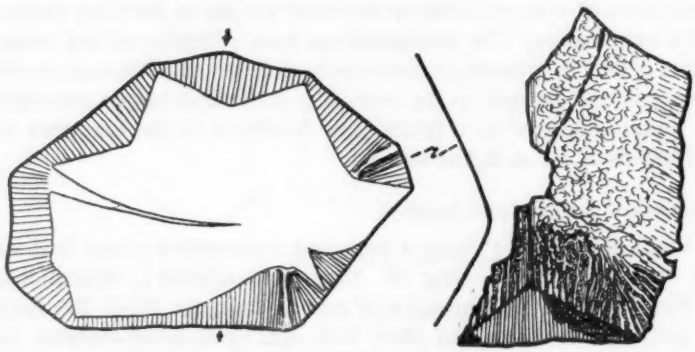
Asterolepis sp.

(Text-fig. 3)

This specimen (No. H 5150) consists of the undamaged external impression of the left mixilateral plate in a hard, buff, pellety quartzite.

[1] Name approved by the Norsk Polarinstitutt for the hitherto unnamed coastal mountain immediately south of Vatnedalen.

It preserves the details of the ornamentation and of the five broad overlap areas and is in outline rather similar to, but larger than, the plate figured by Nilsson (1941, p. 37, text-fig. 19). The plate measures 56 mm. by 36 mm., thus being like Nilsson's specimen (Oslo, No. A 243383) proportionately higher than the same plate in *Asterolepis scabra* (Woodward), *A. maxima* (Agassiz), and *A. ornata* Eichwald, and it is arched to a depth of 11 mm. at its widest point. The overlap areas are prominent and the sensory canal groove extends from the anterior edge towards the dorso-lateral ridge near the posterior edge of the plate. The ornamentation, covering almost the entire surface of the plate, consists of small, distinct, smooth, and rounded tubercles.



3 4

TEXT-FIG. 3.—*Asterolepis* sp. (No. H 5150), left mixilateral plate, × 1. Wijde Bay Series, south of Vatnedalen, Wijdefjorden.

TEXT-FIG. 4.—Antiarch (No. H 5189), ? posterior part of anterior median dorsal plate, × 1½, approximately. Devonian, Hörbyebreen, Dicksonland.

Those situated near the posterior margin of the specimen are somewhat larger than the remainder.

Geological horizon and locality.

Wijde Bay Series ; from scree half way up the north spur of Tage Nilssonfjellet, Wijdefjorden (see Nilsson, 1941, pp. 50–51).

Antiarch *indet.*

(Text-fig. 4)

The interesting features of this specimen (No. H 5189) are its large size and the coarseness of the ornamentation. It is an external impression, almost flat and measuring 102 mm. by 70 mm. Only a fragment of the natural margin of the plate is preserved, but the

coarse reticulate ornamentation changes to nodose ridges some 20 mm. from the margin, and a further portion of margin is indicated by such ridges along the right broken edge of the fossil. At the one end there is some indication of a triangular overlap area, the specimen being gently arched about an axis running from the apex of this. No sensory canal groove is apparent. The features preserved suggest that the specimen is part of the anterior median dorsal plate of an extremely large antiarch.

Geological horizon and locality.

Devonian; from the north lateral moraine of Hörbyebreen, Dicksonland.

Class **OSTEICHTHYES**

Sub-class **Choanichthyes**

Order *RHIZODONTA* (*CROSSOPTERYGII*)

Rhizodontid scales

(Text-figs. 5, 6, and 7)

In the collections are fragments of 16 or more scales preserved

5 6 7

TEXT-FIGS. 5, 6, and 7.—Crossopterygian scales (Nos. H 5160, H 5156, H 5163), external impressions of ornamentation, all × ½. Wijde Bay Series, " Fish Point," Tage Nilssonfjellet, Wijdefjorden.

in varying degrees of completeness (Nos. H 5156, H 5157, H 5160, H 5161, H 5162, H 5163, H 5164, H 5165, H 5167). Almost all are extremely large, the largest being 60 mm. in diameter and 2 mm. thick. They are flat and regular in outline, generally pentagonal, ovoid or almost round. The anterior edges are usually straight, terminating on each side in well rounded " corners ". The external ornamentation of some of the scales greatly resembles that of *Holoptychius*, the anterior part showing fine lines radiating from the centre of the scale and concentric lines parallel to the margin, the posterior and central parts bearing a posteriorly expanding pattern of grooves extending to the margin. The central parts of some scales (e.g. Nos. H 5160, H 5165) bear in addition small rounded tubercles. Other scales (e.g. No. H 5164) do

not possess the pattern of grooves, but only the fine radiating and concentric lines. The different forms of ornamentation do not necessarily imply more than one species. Where the inner surface of the scale is preserved (e.g. No. H 5157) it is flat, except for faint concentric undulations.

These fossils appear to be very large rhizodontid scales, perhaps of *Holoptychius* or a similar fish. This Upper Devonian genus has not, however, been recorded in Vestspitsbergen as yet and the youngest Devonian vertebrate faunas known there are of uppermost Middle Devonian age, equivalent to the Nairn Sandstone of Scotland.

Geological horizon and locality.

Wijde Bay Series ; all except No. H 5165 come from " Fish Point ", south of Vatnedalen, Wijdefjorden ; No. H 5165 comes from scree (243 m. above sea level) on the coastal slope of the north-east spur of Tage Nilssonfjellet, Wijdefjorden.

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GEOLOGY DEPARTMENT,
UNIVERSITY COLLEGE,
EXETER.

CORRESPONDENCE

FLETCHERINA, A NEW NAME FOR A PALAEOZOIC CORAL GENUS

SIR,—Dr. Dorothy Hill has drawn our attention to the fact that the coral generic name *Yabeia* Lang, Smith and Thomas [*Index of Palaeozoic Coral Genera*, Brit. Mus. (Nat. Hist.), 1940, p. 140], proposed for *Cylindrophyllum* Yabe and Hayasaka (*Journ. Geol. Soc. Tokyo*, xxii, 1915, p. 90) *non Cylindrophyllum* Simpson [*Bull. N.Y. St. Mus.*, viii (39), 1900, p. 217], is itself a junior homonym of *Yabeia* Resser and Endo *in* Kobayashi [*Journ. Fac. Sci. Tokyo* (Geol. 2), iv (2), 1935, p. 90 (footnote)], a name introduced for a trilobite. We, therefore, propose the name *Fletcherina* to replace *Yabeia* Lang, Smith and Thomas and *Cylindrophyllum* Yabe and Hayasaka ; the type species is, of course, *C. simplex* Yabe and Hayasaka.

We have chosen the name *Fletcherina* because we consider the genus is at least closely allied to *Fletcheria* Edwards and Haime (*Arch. Mus. Hist. Nat.*, v, 1851, pp. 156, 300). The main differences between the genera appear to lie in the calicular increase and numerous septal striae of the latter, compared with the stated lateral increase and absence of septa and septal spines in *Fletcherina*.

Wang (*Phil. Trans. Roy. Soc. Lond.*, B, ccxxxiv, 1950, p. 206) places *Pycnostylus* Whiteaves, *Placophyllum* Simpson, *Cylindrophyllum* Yabe and Hayasaka (*non* Simpson) and *Synamplexus* Grabau in the synonymy of *Fletcheria*. We reject *Placophyllum* from this synonymy as that genus is a Spongophyllid (cf. Stumm, *Mem. Geol. Soc. Amer.*, xl, 1949, pp. 28, 30). The others are all ampleximorphs ; as with all such genera, their synonymies and relationships are matters of some doubt and difficulty, and must remain so until their type species can be critically re-examined and compared.

Although Edwards and Haime (op. cit.), followed by Nicholson (*On the Structure and Affinities of the "Tabulate Corals" of the Palaeozoic Period*, 1879, pp. 203, 206), referred *Fletcheria* to the Tabulate corals, Wang (op. cit.) placed it in the Rugosa. Not only do we believe him to be right in so doing, but we also place *Fletcherina* in the Rugosa.

W. D. LANG.
STANLEY SMITH.
H. DIGHTON THOMAS.

DEPARTMENT OF GEOLOGY,
BRITISH MUSEUM (NATURAL HISTORY),
CROMWELL ROAD,
LONDON, S.W. 7.

THE UBENDIAN IN WESTERN TANGANYIKA

SIR,—The recently published study of the metamorphic rocks of Karema and Kungwe Bay, Western Tanganyika, by J. Sutton, J. Watson, and T. C. James (1954), is a type of work which is unfortunately all too rare in East Africa ; it represents the results of the detailed mapping of two small areas of the Basement Complex followed by exhaustive and up-to-date laboratory investigation. The areas studied lie in the Ufipa and Ubende regions of which I made a reconnaissance study during the years 1943 and 1944, and published a provisional geological map on a scale of 1 : 300,000 (1950). I do not wish to discuss at present the extremely interesting conclusions regarding the metamorphic complexes arrived at by Drs. Sutton and Watson, but I feel that I must ask them to reconsider the alterations which they propose in my classification of the Basement rocks of Ubende and Ufipa. This country is very difficult of access as, in some 6,000 square miles, there were, at the time of my work, only two motor roads : the geologist has therefore to rely on transport by porters, and since the population has

been partially evacuated owing to sleeping sickness, these are not always easy to obtain. I managed to carry out numerous traverses, but Drs. Sutton and Watson, during the limited time at their disposal, were mainly dependent for their knowledge of the geology of the whole area on specimens collected by others, including myself. During a reconnaissance it is natural to collect the exceptional types of rock, and hence the study of such a collection may tend to overemphasize the deviations from the general rule.

In the paper by McConnell, four major sub-divisions are proposed : the Ubende and the Wakole Series, which are regarded as, respectively, younger and older members of one system ; the Mahali Gneisses ; and the Ufipa Gneiss Complex. Sutton and Watson regard these four groups as equivalent and propose to regard all the basement rocks in this area as one series, which they call " Ubendian ". This is a considerable generalization, and I would like to make a strong plea for caution. The name " Ubende Series " was introduced by McConnell, and applied to a well-defined group of rocks which appears to be the youngest element of the Basement Complex in the area ; and the orogeny which closed the cycle was termed the " Ubendian Diastrophism ". I would like to see these terms left with their original meaning. If a term to include all the Basement rocks of Ufipa and Ubende is needed, some other local geographical name should be chosen.

The Ubende and Wakole Series were distinguished by McConnell because they differed in lithological constitution and metamorphic grade. The two series outcrop as ribbons running parallel in a N.W.–S.E. direction for eighty miles ; they are separated by a fault which is accompanied by transfused mylonites, which are almost certainly of Precambrian age, although the lines of truncated spurs indicate that relative uplift of the Wakole rocks took place in late Tertiary or Recent times. The most widespread rock in the Wakole Series is a biotite-kyanite-schist : garnets are sometimes very numerous and attain ¼-inch diameter. Amphibolites and hornblende-gneiss contain much garnet as a rule ; metaquartzites are also frequent and commonly contain garnet, and some varieties carry hornblende. The Ubende Series is chiefly composed of hornblende-gneiss and amphibolite with little or no garnet, white crystalline quartzites in which no garnet was found, crystalline limestones and metacalcareous rocks without garnet. Charnockitic rocks and pyroxene-bearing intrusives carrying garnet occur locally but are exceptional. Kyanite, which is so frequent in the Wakole Series, is only found in a very few localities in the Ubende rocks. The Mgambo-Katumbe rocks studied by Drs. Sutton and Watson are considered by them to represent intrusions and carry much garnet and a little kyanite. These rocks differ so much from the normal Ubende Series as to suggest that more regional work is required to prove what their relations are with the surrounding rocks.

As a result of their field work and of their study of my collections, Drs. Sutton and Watson conclude that since many types of rock are common to both Ubende and Wakole Series there is no reason for making a distinction. When both formations are regarded as a whole, however, the differences in lithological constitution and metamorphic grade are important, and should be indicated in the nomenclature. I agree that metamorphic grade is not a criterion of age, but when two formations are contiguous for a distance of some eighty miles, and continually show a striking difference in grade of metamorphism, it is difficult to avoid the conclusion that one has had a more complex metamorphic history than the other. A good section across the strike of both series can be examined by following the motor road from Sibwesa to Ikola. From Sibwesa westwards the road traverses the garnet and kyanite-rich rocks of the Wakole Series, and a panning from any stream would yield much garnet and kyanite. The metaquartzites and hornblende-gneisses all carry garnet, and usually in considerable quantity. On passing the faulted boundary at the western limit of the Wakole highlands no more garnet or kyanite is seen. The typical hornblende-gneiss of the Ubende Series appears without any garnet ; talc-

schists are also crossed, and a wide belt of crystalline limestone near Ikola is quite free of garnet.

In the paper by Sutton, Watson, and James, a map is given (figure 15, page 60), which is rather misleading. On this map a comparison of kyanite, charnockite, and garnet-augite-granulite localities in the Ubende and Wakole Series is given. In the Ubende Series six " Ks " indicating kyanite localities are given as opposed to five " Ks " (disregarding the problematical enclave in the south of the map) in the Wakole band. Of the five Wakole kyanite localities, two indicate the place where a single band of the characteristic biotite-garnet-kyanite-schist crosses the Sibwesa-Ikola motor road. The geological map accompanying McConnell's paper shows, however, that an outcrop of 70 square miles of biotite-garnet-kyanite-schist was mapped on the various traverses, and if the probable outcrops were joined between the traverses, the area of outcrop would amount to over 200 square miles.

In addition to the Ubende and the Wakole Series, Sutton, Watson, and James wish to include the Mahali Gneisses, and the whole of the Ufipa Gneiss Complex in their Ubendian. The Mahali Gneisses form the Mahali Mountains and outcrop over an area of about 360 square miles. They are very homogeneous in lithology and structure, and the fact that their boundary with the Ubende Series is not a simple one may be due to tectonic complication masked by a later metamorphism. In fact, the boundary is undoubtedly a very important line of faulting which has continued moving at intervals from the date of the Ubendian Diastrophism and down to Recent times. As regards the great Ufipa Gneiss Complex, I should be surprised if it proves to belong to a single series, but much work has been done since my preliminary traverses and the question must be left to the future.

It will be many years before any general agreement can be reached on the subdivision of the Basement Complex into cycles and systems ; I would like to suggest, therefore, that terms implying regional correlation should only be introduced when the facts are incontrovertible. In this letter I have tried to indicate as briefly as possible why I think that the Ubende and Wakole Series should be regarded as separate entities, and why the term " Ubendian " should be restricted to the sense in which it was originally used.

R. B. McConnell.

Geological Survey,
Lobatsi,
Bechuanaland Protectorate.

14th January, 1955.

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REVIEW

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The reappearance of this book which has been out of print for some years is very welcome. It is an excellent guide to the study of rocks in thin slices for those who take general courses in geology or specialize in other branches than petrology ; and all rocks, igneous, sedimentary, and metamorphic, are covered in one volume at a reasonable price. Some slight revision has been made in the text, and the footnote references, a valuable feature, have been brought up to date.

L. H.

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